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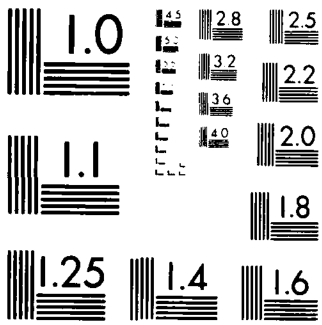

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Report No. CG-D-33-84

ATLAS OF THE BEAUFORT SEA

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AD-A149 545

FINAL REPORT
October 1984

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16. Abstract

This is a reference document on oceanography, meteorology, ice and climatology. The oceanography section contains information for circulation, tides, riverine input, ice conditions, storm surges and bathymetry of the Alaskan Beaufort Sea. From review of information on meteorology, climate, ice conditions, and oceanography, maps have been generated showing circulation in two typical wind conditions: ENE wind at 10 knots and NW storm wind at 30 knots. These maps show tides, storm surges, bathymetry and river discharges as well as charts of mean ice drift over time. The meteorology section contains information on winds, storm surges and waves. Included is a rapid manual forecast system for estimating the height of a storm surge.

The ice section gives information on the ice zones, including the annual ice cycle within the nearshore area, the freezing and breakup of nearshore ice, and the movement of the pack ice.

The climatology section includes information on the arctic climate, temperature information (including wind chill charts), visibility, and precipitation.

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METRIC CONVERSION FACTORS

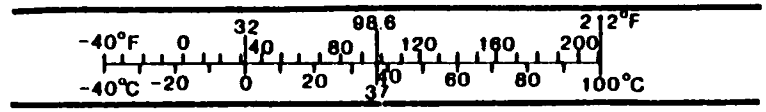
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13 10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION A
OCEANOGRAPHY

1.0 INTRODUCTION

In the event of an oil spill in the American Beaufort Sea or on its shoreline, the Coast Guard predesignated On-Scene Coordinator (OSC) is responsible for ensuring that timely and adequate containment and removal actions are taken. In most cases, especially in this region, responsible parties will probably take the appropriate cleanup action and the Coast Guard OSC's role will be to monitor these actions. If the responsible party's actions are non-existant or inadequate, or when the responsible party is unknown, the OSC may initiate cleanup action using Federal pollution funds. In either case, the OSC will be operating in a unique, remote, and hostile environment, where cleanup actions are expensive and environmental conditions are very sensitive.

In order to effectively respond to a spill on the Beaufort Sea, information on the conditions that could affect oil spill behavior and oil cleanup is essential. This Environmental Atlas has been compiled to provide the OSC with this information for the North Slope of Alaska. This Atlas is designed so that the necessary information can be found quickly and is easily understood. It is important to emphasize that an Atlas, no matter how complete, cannot replace actual field reconnaissance. It does, however, provide a means by which the user can become familiar with environmental conditions in the area. The Atlas also provides reference material for decision making in response needs. It can also help the OSC, who may not have special oceanographic training, obtain the necessary information in a straightforward manner.

The Atlas is divided into four sections: Oceanography, Meterology, Ice, and Climatology. It is designed to

answer two questions the OSC responding to an Arctic oil spill might ask: (1) Into what areas can the spill be expected to drift and how soon; and (2) What environmental conditions will personnel be facing at the spill cleanup site?

Current weather conditions and the specific geographical location of the spill source would form the Atlas entry points for calculating estimated trajectories. This information is located in the oceanography section.

Questions regarding expected environmental conditions can be answered from information available from the Atlas' meterology, ice, and climatology sections. These sections contain comprehensive tables on mean, average, and frequency of occurrence of environmental conditions and, therefore, operational conditions that response personnel can expect to encounter. The Atlas has been prepared so that it may be updated and expanded as the need arises.

2.0. THE PHYSICAL ENVIRONMENT

The physical setting of the Beaufort Sea is such that the Beaufort Shelf is virtually completely covered by ice for all but two to three months of the year. The ice cover tends to insulate the underlying waters from both the atmospheric temperature and wind fields and to provide a source of dense brine in the winter and fresh meltwater in the spring and summer. Spring melting of the sea ice coincides with a massive influx of freshwater run-off from the land, both of which tend to stabilize the upper surface water, retain solar heat, and further enhance sea ice melting. Depending on the wind field for a particular year, the open water lead along the coastline may be as narrow as 10 km or as wide as 100-200 km and extend the entire length of the Beaufort Sea. It is this open water portion of the Beaufort to which this document is applicable.

Several studies (Aagaard, 1981; Matthews, 1981; Hachmeister and Vinelli, 1983) have concluded that the major driving mechanism for water exchange and transport on the eastern Beaufort Sea inner shelf, including the nearshore and lagoon systems, is derived from atmospheric forcing. The wind field determines both the direction and the intensity of the longshore current, the retention or removal of warm nearshore waters from the coast, the vertical mixing and horizontal exchange of lagoons, and (probably most importantly) the movement of ice and water on, off and along the nearshore region. The wind field in the western Beaufort is typically dominated year-round by easterly or northeasterly winds, whereas the eastern Beaufort exhibits dominant easterly and northeasterly winds in the summer and westerly and southwesterly winds in the winter. In the western Beaufort this implies that year-round mean currents will be very similar to prevailing winds, primarily from the east. In the eastern Beaufort, winds are bimodal with prevailing winds from the west through the fall and winter, and from the east in the spring and summer. Storms tend to produce winds from the northwest in both regions and

can result in strong longshore currents, especially in the fall when a large expanse of open water exists along the Beaufort coast.

The shelf in the central and western Beaufort is relatively narrow with the shelfbreak typically occurring 80-90 km offshore. Lagoon/nearshore systems which characterize this region of the Beaufort coastline have been termed "open", that is, open to the wind-driven longshore transport and to onshore/offshore exchange through numerous large openings in their offshore barrier island systems.

In the eastern Beaufort the shelf is slightly more narrow (approximately 40-60 km). The barrier island systems tend to be closer to the coastline, more extensive, and more closed to direct flowthrough by the longshore current, thus limiting the exchange of water between the longshore currents and the lagoons to a small number of openings in the barrier island system (limited exchange lagoons). In many of these limited exchange lagoons, the exchange of water is restricted to one or two major entrances. These lagoons, which typically have very narrow entrances and poor exchange characteristics, exhibit highly localized current jets at the entrances in response to periodic tidal forcing and have been termed "pulsing" lagoons.

Patterns of water movement on the shelf tend to exhibit strong continuity in the longshelf direction (paralleling isobaths) and large zonal variability in the cross-shelf sense (crossing isobaths). Following Aagaard (1981), the region of the shelf landward of the 40-m isobath which exhibits one set of characteristics will be referred to as the "inner" shelf; the region seaward of the 40-m isobath will be termed the "outer" shelf. That area of the inner shelf landward of the 20-m isobath with activity marked by the ice and/or surface waves, and which exhibits higher summer temperatures and lower salinities than the water between 20 and 40 m, is referred to as "nearshore" after Truett (1981).

GENERAL CIRCULATION

3.0. GENERAL CIRCULATION

Three current regimes are present along the Beaufort coastline (Figure 1). In deeper waters, the clockwise Beaufort Gyre moves waters from the Canadian Basin westward. Gyre velocities reach 5-10 cm/s north of the Alaskan coast (Aagaard, 1979). Inshore of the 40- to 50-m isobath currents are wind-driven and generally parallel to the coast (USDI, 1979). The Alaska Coastal Current enters the Beaufort Sea along the Barrow Sea Valley. The current jet then follows the 200-m isobath through the Alaskan Beaufort Sea (Aagaard, 1983; Thomas, 1983). Velocities are usually on the order of 15-25 cm/s to the east, but frequent reversals in direction result in a lower net eastward movement of 7 cm/s. In the nearshore region, mean currents are primarily wind driven and flow from 15-25 cm/s.

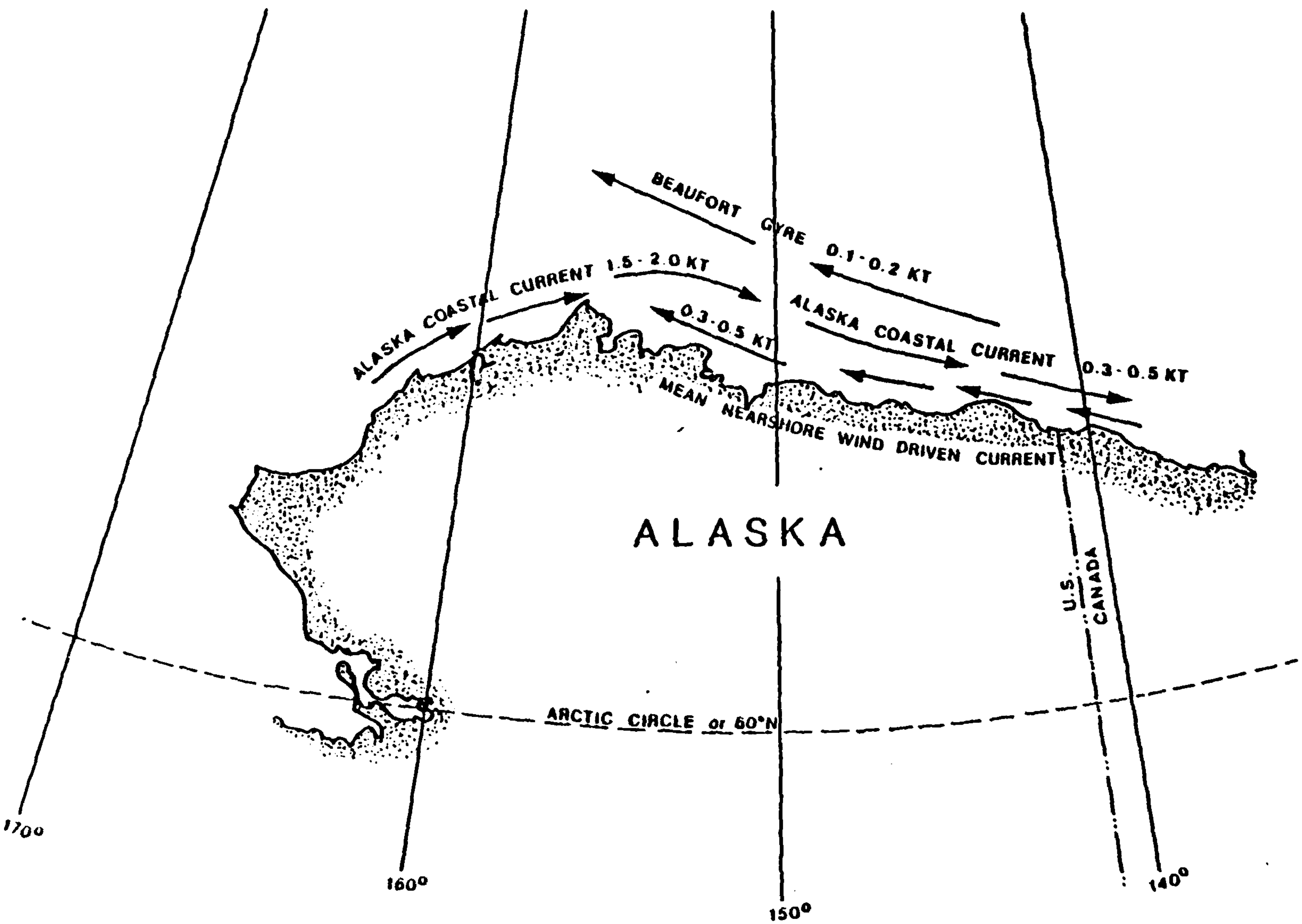


FIGURE 1 - GENERAL CIRCULATION PATTERNS IN THE BEAUFORT SEA

(1 knot = 0.5148 m/s)

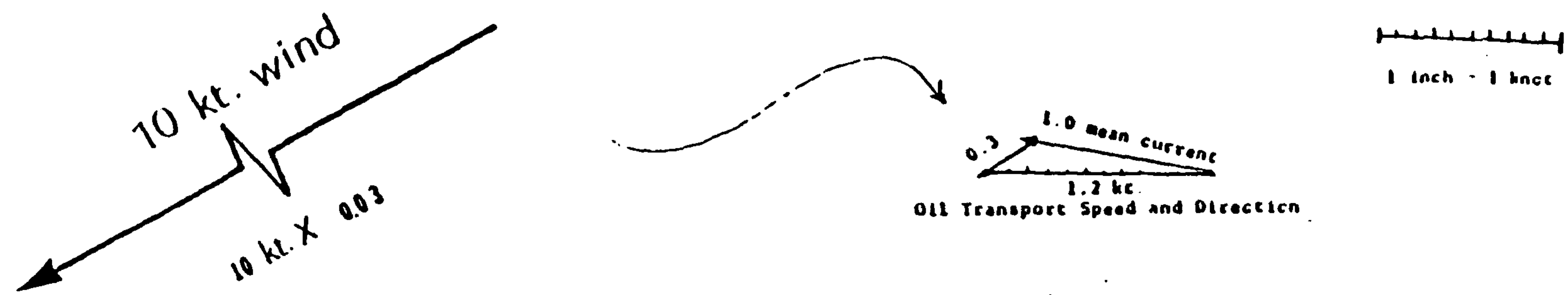
3.1 OIL SPILL TRANSPORT

Current speeds in the Continental Shelf and Lagoon and Nearshore sections are intended to represent mean open water conditions with 10 kt winds from the northeast and storm conditions with 30 kt winds from the northwest. In the case of the mean conditions, current speeds which are displayed on the figures are primarily wind induced and may be rescaled for higher or lower wind speeds by the included formula. Current directions typically follow local topography and will not vary significantly for either different wind speeds or wind directions than those indicated.

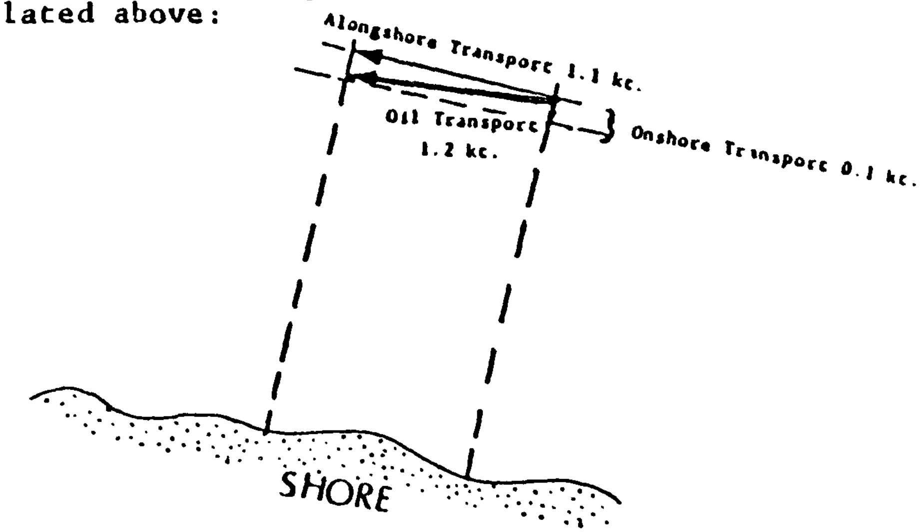
A simple vector technique is presented below to quickly estimate the near surface transport of oil given the mean current field and the wind vector. This technique provides a rough approximation of resulting oil transport speed and direction which will be useful in estimating times and locations of spill landfalls.

Mean currents in the Beaufort Sea typically follow the bottom topography. Estimates of oil transport, however, will vary from the mean current field and instead follow a more wind driven pattern. This transport may be estimated by adding 3 percent of the wind speed to the mean currents as shown in Illustrations 1 and 2.

(1 knot = 0.5148 m/s)



The following technique may be used for determining the longshore and onshore transport components of the oil which was calculated above:



Note: This technique is most effectively used in the field by utilizing clear overlays (such as mylar or acetate materials) to produce a complete transparent overview for the region of concern. (See next page for an example of this method.)

ILLUSTRATION 1 - TECHNIQUE FOR DETERMINING THE TRANSPORT OF OIL.

(1 knot = 0.5148 m/s)

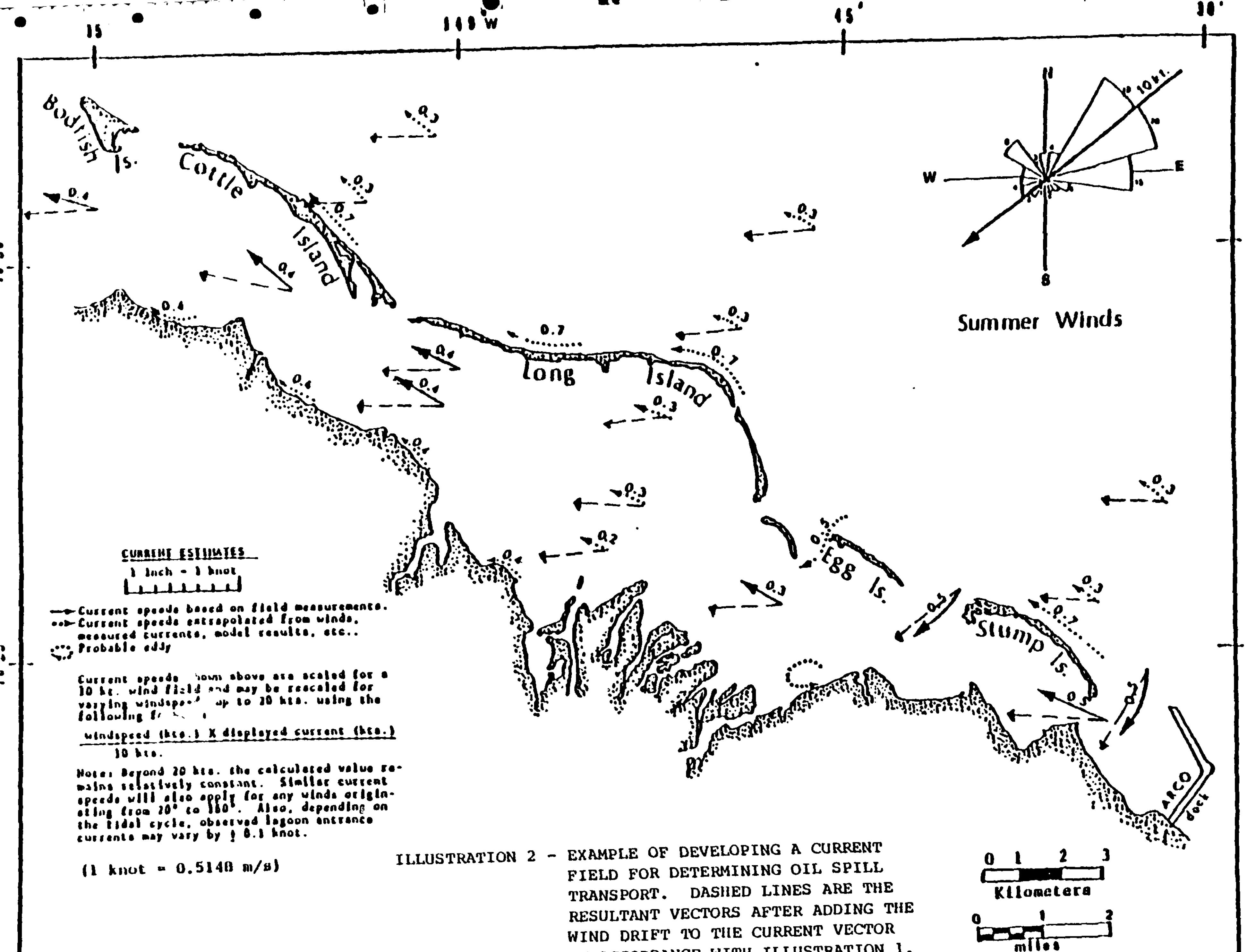


ILLUSTRATION 2 - EXAMPLE OF DEVELOPING A CURRENT FIELD FOR DETERMINING OIL SPILL TRANSPORT. DASHED LINES ARE THE RESULTANT VECTORS AFTER ADDING THE WIND DRIFT TO THE CURRENT VECTOR IN ACCORDANCE WITH ILLUSTRATION 1.

CONTINENTAL SHELF CIRCULATION

4.0. CONTINENTAL SHELF CIRCULATION

4.1. Outer Shelf

The most prominent hydrographic feature on the outer Beaufort Shelf is the summer subsurface temperature maximum typically observed at or seaward of the 40-m isobath. This temperature maximum is associated with an eastward flowing core of water originating in the Bering Sea, referred to as Alaskan coastal water. Alaskan coastal water can typically be seen as far east as 150 °W longitude where it mixes with local surface water. The nearshore limit of this water typically follows the 40- to 50-m isobaths throughout the American sector of the Beaufort Sea during the summer months and provides a good demarcation zone for separating the inner and outer shelf regimes.

The mean circulation pattern of subsurface waters on the outer shelf is predominantly eastward, paralleling the isobaths. Aagaard (1981) and others have suggested that this mean flow, observed during both summer and winter months, is driven by the difference in sea level between the Atlantic and Pacific Oceans and extends across the entire Beaufort Shelf, possibly as far east as Baffin Bay. There is some evidence that surface waters above this eastward flow may have mean westward motion, although no direct current measurements confirming this hypothesis have been made. Currents in both the surface and subsurface waters can be affected by periodic meteorological forcing with typical periods on the order of 3-10 days and may show reversals in the mean eastward flow. These reversals are in turn correlated with deep upwelling events on the outer shelf.

4.2. Inner Shelf

Although current measurements on the inner shelf are extremely sparse due to the difficulty of maintaining moorings in the presence of sea ice, recent drifter data reported by Matthews (1981) and current meter measurements made by Aagaard (1981) give some indication of

both open water and ice-covered water movements. It has been generally agreed that water movement on the Beaufort inner shelf is wind-driven. This hypothesis is further supported by Matthew's drifter data which suggests that the motion of all recovered drifters resulted from prevailing wind-driven currents, both for open water and under-ice releases. Drifter travel times and computed current speeds were consistent with values of approximately 3-4 percent of the wind transport for the same periods with under-ice motion being significantly less.

If these conditions can be extrapolated to the eastern Beaufort Sea, then current patterns on the inner eastern shelf would be expected to show a more even distribution of both easterly and westerly currents. As discussed previously, prevailing winds along the central and western Beaufort are from the ENE during all seasons. However, in the eastern Beaufort the distribution of winds is more bimodal. At Barter Island, for example, the average winds are from the ENE to E for 35 percent of the time and from the WSW to W for 25 percent of the time (Seary and Hunter, 1971) with winds predominantly from the west during the winter and from the east during the open water season (Brower et al., 1977). If the inner shelf waters in the eastern Beaufort follow the local wind patterns one could expect to observe mean current patterns to the east in the winter and to the west in the summer following local wind patterns.

In the western Beaufort, transverse circulation would be predominantly offshore in the upper layers and onshore in the lower layers due to the predominantly ENE winds. In the eastern Beaufort, the effect would be similar to the western Beaufort pattern during easterly wind events, and opposite (onshore flow in the upper waters and offshore in the lower layers) during westerly wind events. Seasonal variability would

therefore show a net offshore transport of surface waters in the summer and onshore transport in the winter in the eastern Beaufort.

Longshore transport of water has also been demonstrated to be primarily wind driven with alongshore currents which follow the local bathymetry at roughly three percent of the wind speed. In the western Beaufort, this implies mean longshore transport to the west with easterly reversals *occurring* as *mean* wind conditions are modified by the passage of weather systems across the Beaufort. In the eastern Beaufort mean weather patterns are bimodal in nature. Summer longshore transport is dominated by mean westward motion with reversals to the east as weather systems move through the area. Fall and early winter conditions show mean eastward water movement in this area with very high eastward transport and wind-induced set-up associated with fall storm systems. Westward transport also may be observed to accompany periods of easterly winds. The maps following (Figures 2-8) show mean surface currents during 10 kt NE and 30 kt NW wind conditions. Wind roses were generated from Brower et al. (1977) using percent occurrence of mean summer winds at Prudhoe Bay. The pie-shaped wedges are labeled with the percentage frequency of occurrence of wind. Thus 15% of the time the wind is easterly, 20% of the time it is ENE, etc.

(1 knot = 0.5148 m/s)

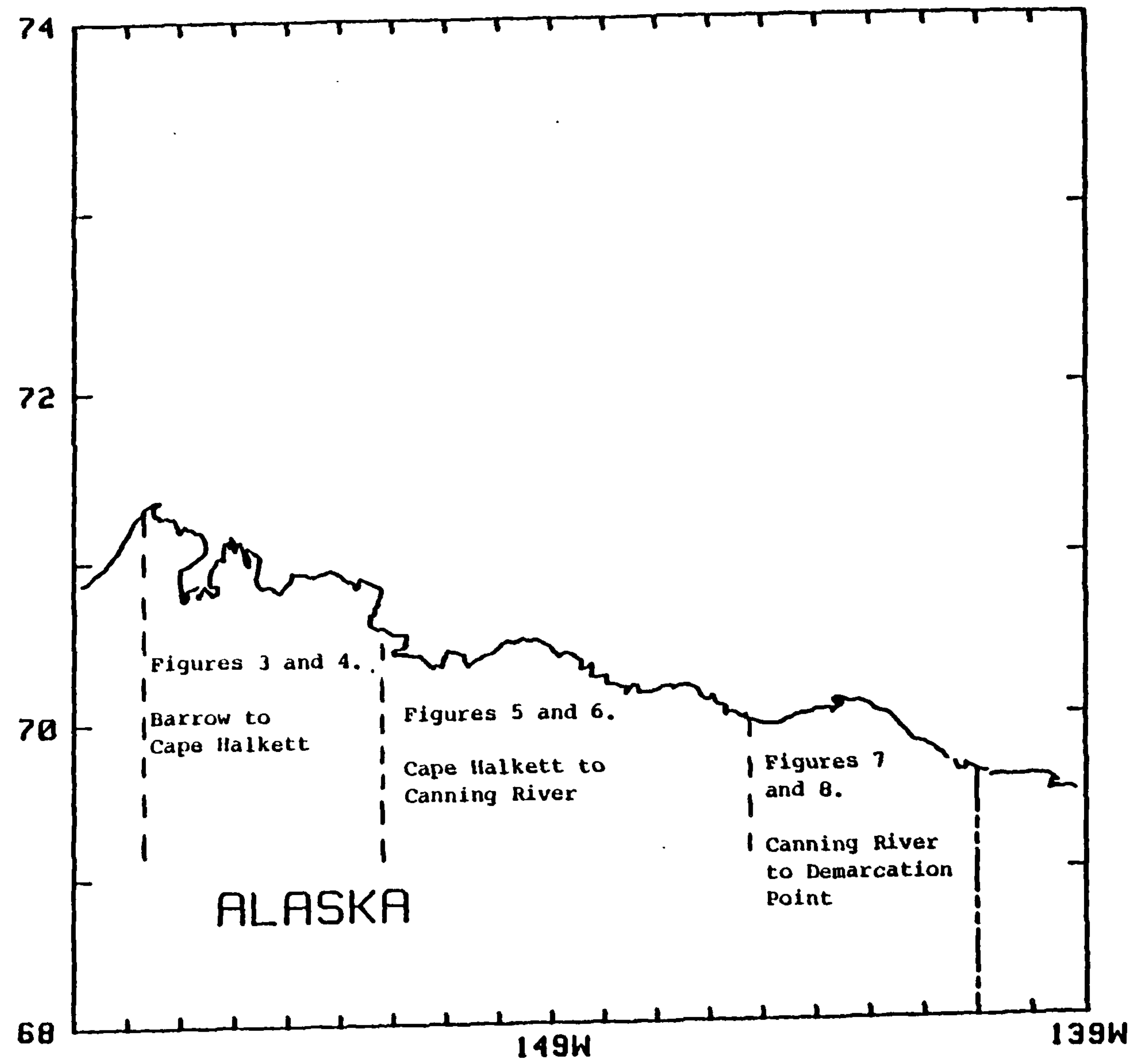
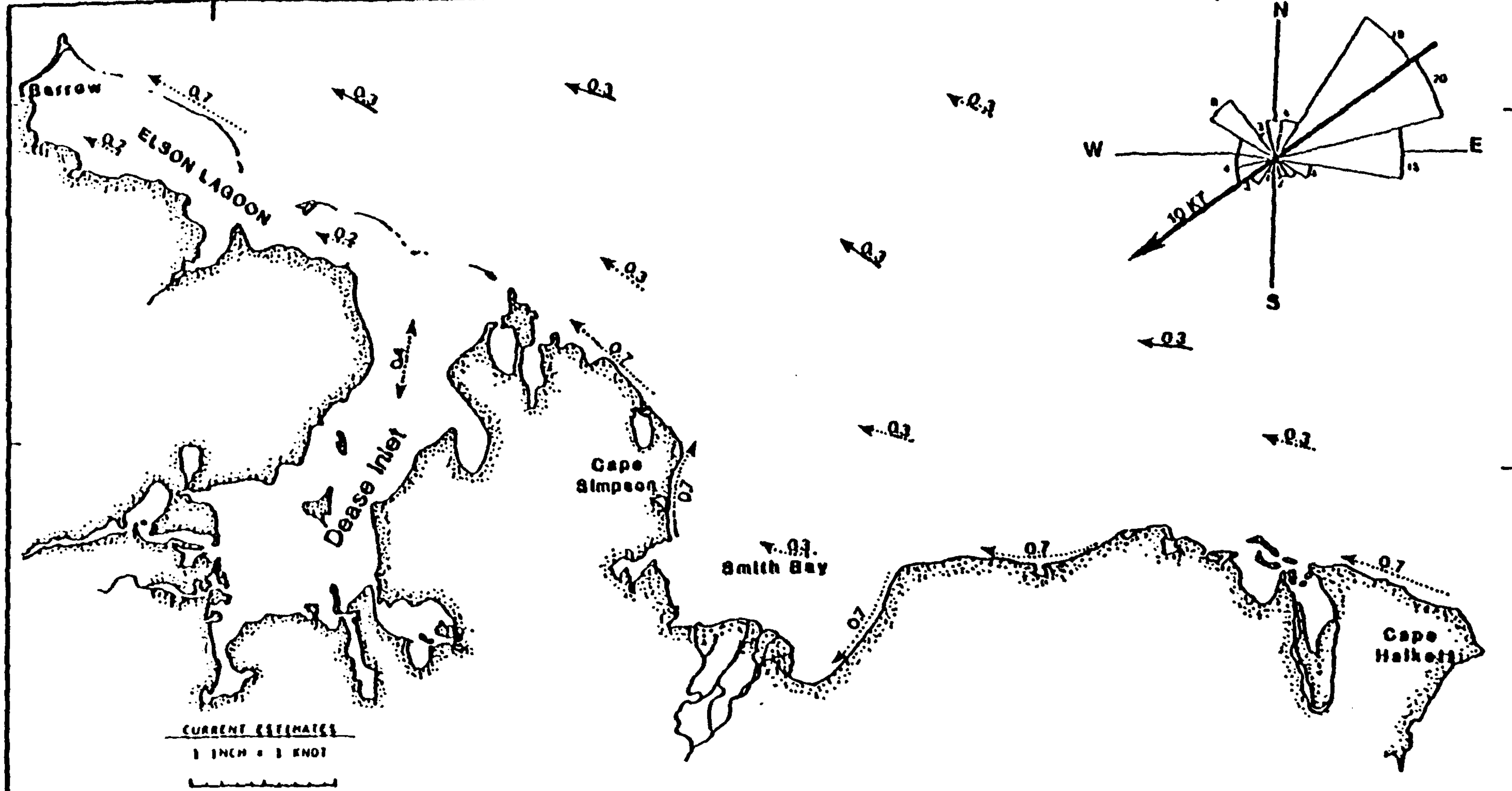


FIGURE 2 - LOCATIONS OF CURRENT ESTIMATE CHARTS FOR CONTINENTAL SHELF CIRCULATION.



CURRENT ESTIMATES

1 INCH = 1 KNOT

→ CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
··→ CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
PROBABLE EDDY.

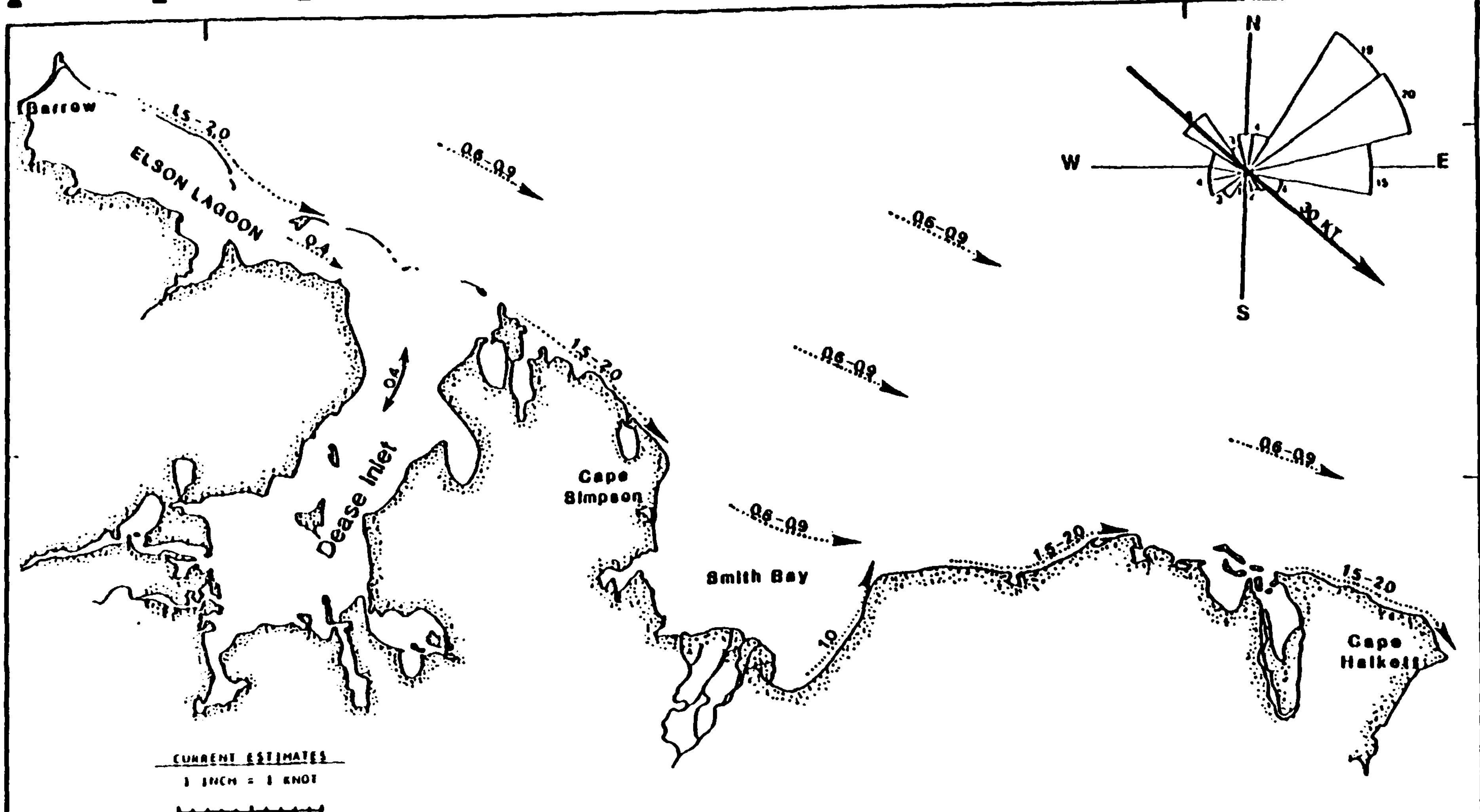
CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 10 KT. WIND FIELD AND MAY BE RESCALED FOR VARYING WIND-SPEEDS UP TO 20 KTS. USING THE FOLLOWING FORMULA:

$$\frac{\text{WINDSPEED (KTS.)} \times \text{DISPLAYED CURRENT (KTS.)}}{\text{10 KTS.}}$$

NOTE: BEYOND 20 KTS. THE CALCULATED VALUE REMAINS RELATIVELY CONSTANT. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS ORIGINATING FROM 20° TO 180°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT.

(1 knot = 0.5148 m/s)

FIGURE 3 - CURRENT ESTIMATES FOR BARROW TO CAPE HALKETT REGION UNDER 10 KT. NE WIND.



CURRENT ESTIMATES

1 INCH = 1 KNOT

CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
PROBABLE EDDY.

CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 30 KT. WIND FIELD. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS OF THIS STRENGTH ORIGINATING FROM 280° TO 340°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT FOR WINDS OF LESS THAN 20 KTS. IN THE WESTERN QUADRANT, CURRENT SPEEDS MAY BE ESTIMATED USING THE CURRENT DIRECTIONS GIVEN IN THIS FIGURE AND THE CURRENT SPEEDS FOR THE 10 KT. WIND SHOWN IN THE PREVIOUS FIGURE.

(1 knot = 0.5148 m/s)

0 4 8 16
Kilometers
5 0 5
Miles
N

FIGURE 4 - CURRENT ESTIMATES FOR BARROW TO CAPE HALKETT REGION UNDER 30 KT. NW WIND.

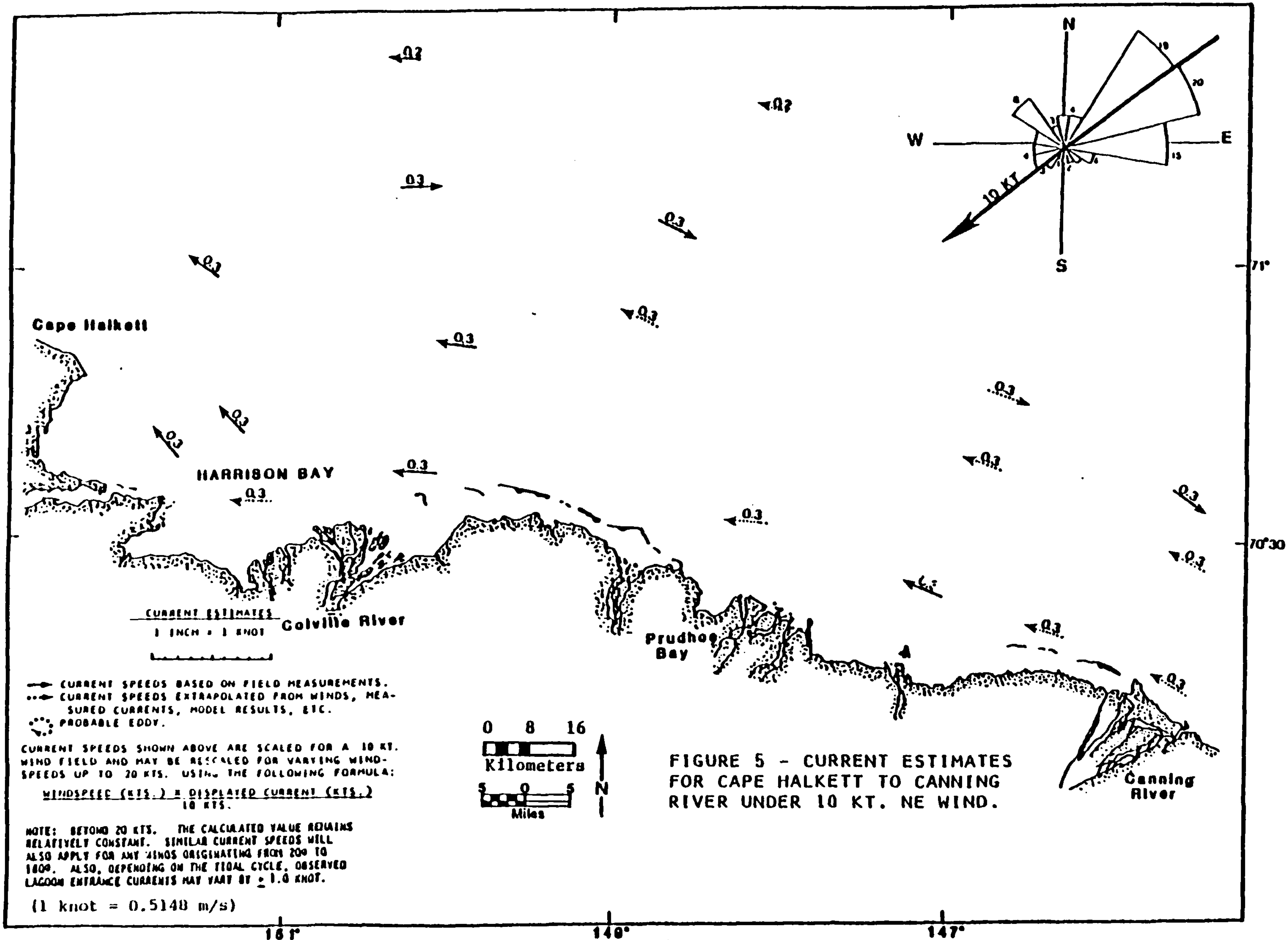


FIGURE 5 - CURRENT ESTIMATES FOR CAPE HALKETT TO CANNING RIVER UNDER 10 KT. NE WIND.

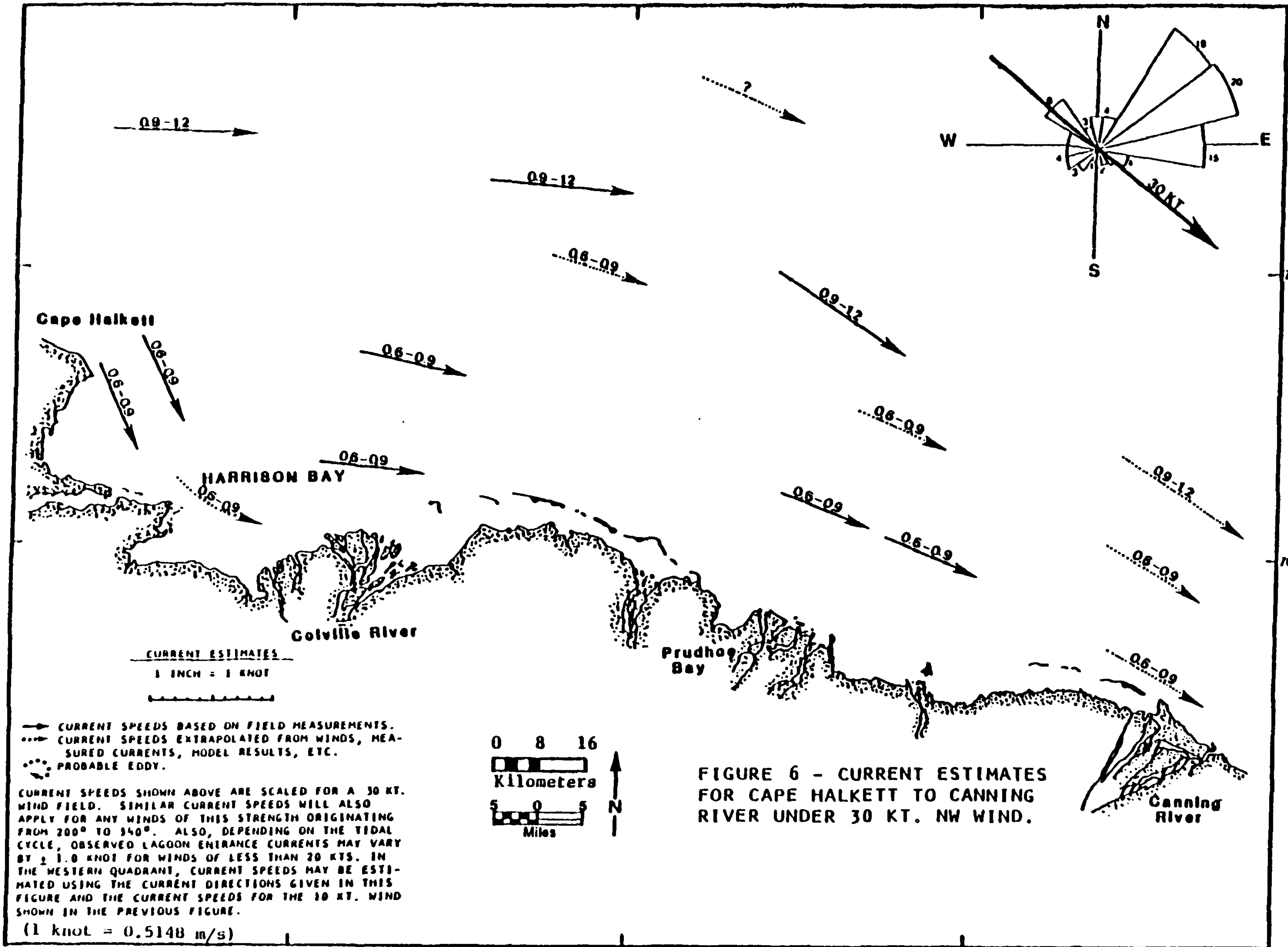


FIGURE 6 - CURRENT ESTIMATES FOR CAPE HALKETT TO CANNING RIVER UNDER 30 KT. NW WIND.

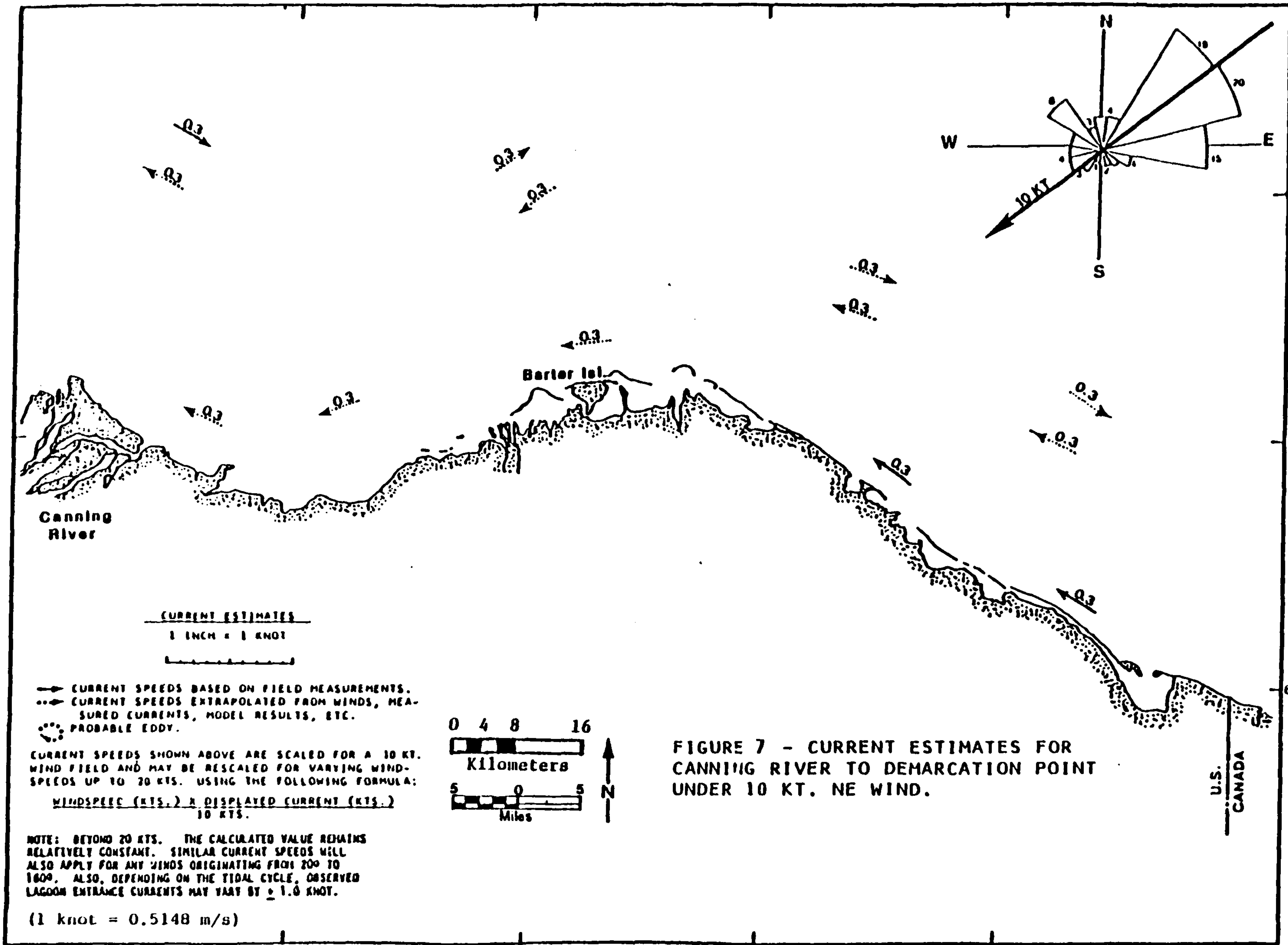


FIGURE 7 - CURRENT ESTIMATES FOR CANNING RIVER TO DEMARCATION POINT UNDER 10 KT. NE WIND.

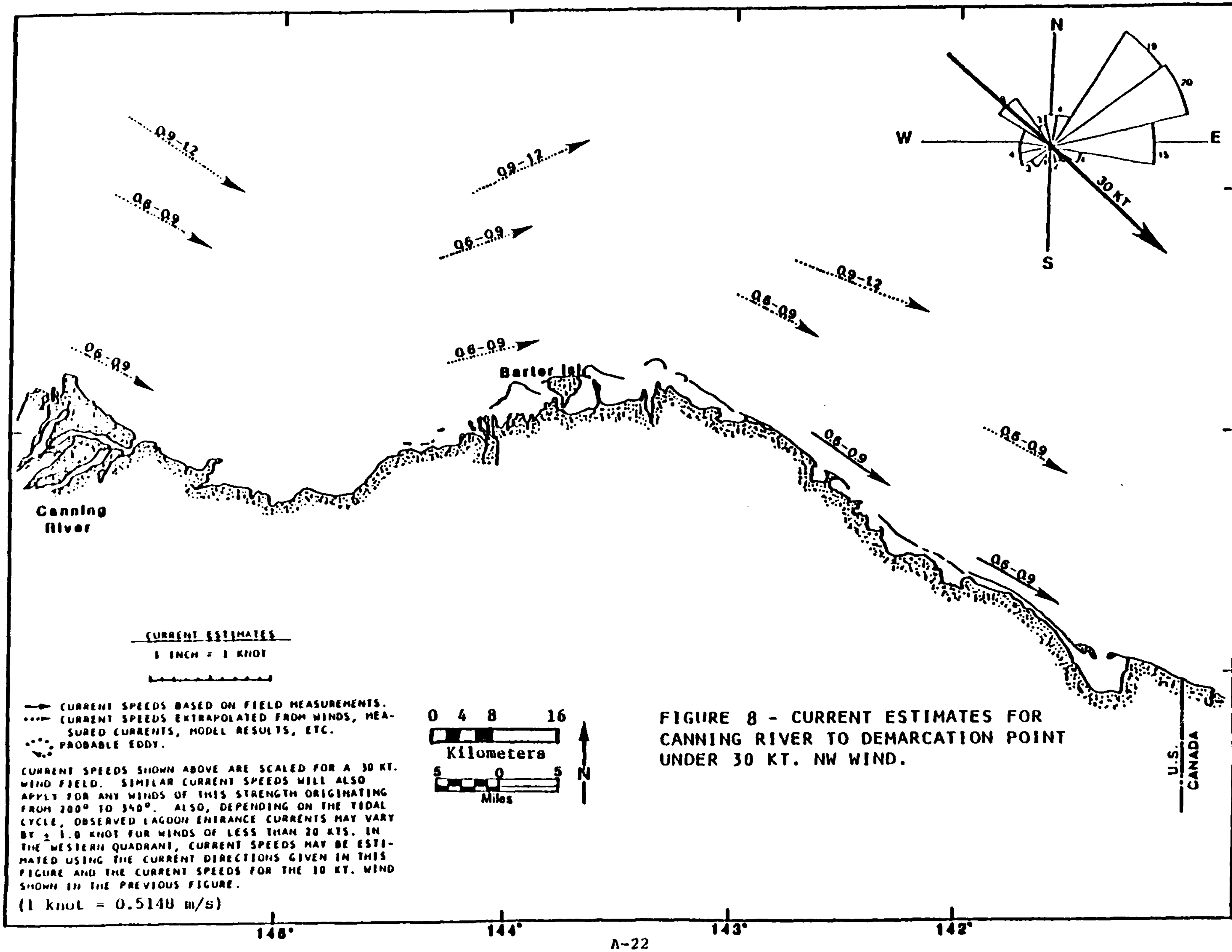


FIGURE 8 - CURRENT ESTIMATES FOR CANNING RIVER TO DEMARCATION POINT UNDER 30 KT. NW WIND.

LAGOON &
NEARSHORE CIRCULATION

5.0. LAGOON AND NEARSHORE CIRCULATION

Considerable research has been accomplished in the central and eastern Beaufort nearshore and lagoon regions (Matthews, 1979; Hachmeister and Vinelli, 1983). Observed currents in the lagoons and nearshore appear to be predominantly wind-driven with current speeds approximately 3-4 percent of the wind speed. Superimposed on these mean wind-driven currents are short-term effects of storm passages and tidal effects which are dominated by diurnal (M2) forcing. Circulation patterns and exchange properties of nearshore and lagoon/barrier island systems on the eastern and western Beaufort Shelf show many dissimilarities. Observed differences may be attributable both to differences in coastal and lagoon geometries and to differences in their surrounding external physical environments.

The basic lagoon types appearing on the Beaufort coastline are illustrated in Figure 9. The first type discussed in this report is the open lagoon, i.e. that which is open to longshore transport as well as to cross-shelf exchange between multiple large openings in the barrier islands.

The second lagoon type discussed is the pulsing lagoon, i.e. that which has one major entrance through the barrier islands. The pulsing lagoon is closed to longshore current throughput; exchange with the nearshore waters occurs primarily via tidal pumping of water through a single major entrance, with less exchange also occuring through shallow breaks in the barrier islands. One or more small rivers or streams typically empty into each type of lagoon providing a source of freshwater in early spring.

The third lagoon type is termed a limited exchange lagoon in that it has only limited longshore current throughput via several larger openings in the barrier island system. These lagoons may or may not exhibit pulsing effects due to tidal pumping. Each lagoon type is discussed below, using specific geographic examples of each.

5.1. Open Lagoons

The most extensively studied example of an open lagoon system is Simpson Lagoon. During summer easterly wind conditions, nearshore water enters the lagoon

through eastern and central openings in the barrier islands and is advected through the lagoon in a manner similar to the wind-driven longshore transport seaward of the barrier island chain. The multiple large openings in the lagoon barrier island chain and the open western end allow considerable flowthrough of the nearshore waters. Exchange is therefore largely due to advection of new water masses through the lagoon rather than input/local mixing/output.

Tidal effects are superimposed upon the wind-driven component of the circulation and periodically modulate that component's effect. Depending on the strength of the wind-driven currents in a particular opening of the barrier island chain, the tide may only modulate the mean flow in the entrance, or it may actually reverse the flow during the opposing cycle of the tidal current as has been observed in Angun Lagoon (Hachmeister and Vinelli, 1983).

When both mean wind-driven and tidal components of the circulation pattern are acting simultaneously, the effect is a pulsing flow pattern in the lagoon with a mean flow from east to west through the lagoon. Matthews (1979) has estimated that the flowthrough occurs at 3-4 percent of the mean wind speed, indicating lagoon water turnover on the order of 3-4 days for mean wind conditions of 10 kts. During these conditions, a net wind-driven transport of waters east to west through the lagoon is accompanied by some offshore transport of the warm fresh surface nearshore waters and replacement by cooler saltier offshore waters at depth. Tidal currents then selectively introduce this nearshore water to the lagoon interior at each entrance on the successive flood tides. On ebb tides, the net westward flow is reduced and lagoon waters collect near the eastern entrances of the lagoon to form pools of warmer fresher water. On successive flood and ebb tides, these pools of alternating cooler saltier nearshore water and warmer fresher lagoon water (formed by mixing of nearshore water from previous cycles and freshwater from river runoff) experience a net westward transport through the lagoon interior.

During mean westerly winds (wind direction to the east), a reversal in the wind-driven current direction from westerly to easterly (current to the east) is observed and a net onshore transport of surface waters occurs which holds the warm, less saline lagoon waters in the nearshore. The current reversal is accompanied by the disappearance of the alternating nearshore and lagoon water masses (as nearshore and lagoon waters become identical) and observance of uniform warm intermediate-salinity water in the lagoon. Persistent westerly winds also result in a rise in the mean sea level which may be as great as several meters in some cases (see Section 8.0). The reestablishment of mean winds and westward lagoon flow would begin to produce an observed differential between lagoon and nearshore waters. The rate of water transport through the lagoon appears to be approximately the same both before and after the abrupt wind shift. During westerly winds, however, nearshore and lagoon waters appear to be identical while during easterly winds, they exhibit differences in both temperature and salinity. The lagoons in the western Beaufort from Barter Island to Pt. Barrow are almost all of the open type similar to Simpson Lagoon.

5.2. Pulsing Lagoons

Figure 10 illustrates the combined wind and tidal effects on the exchange of lagoon and nearshore water for a pulsing lagoon using Angun Lagoon and Pokok Bay as examples. Mean summer conditions are illustrated in this figure with winds predominantly from the east. In a manner similar to the open lagoon case, easterly winds result in somewhat higher nearshore salinities and lower nearshore temperature for exchange with the lagoon. In addition, circulation in the lagoon itself may depend on the lagoon geometry with greater mixing observed for a lagoon with the geometry of Pokok Bay than for a lagoon with the longer more narrow shape of Angun Lagoon.

During westerly winds, the fresher warmer nearshore water is maintained on the coast and advected eastward in the longshore current as in the open lagoon case. However, when easterly winds are reestablished the nearshore waters cool

as warm water is driven offshore and the pulsing effects of cool-water-in/mixing/warm-water-out is observed. Nearshore current reversals have been observed to occur in as little as several hours (Hachmeister and Vinelli, 1983). Because there is no net flowthrough of the waters entering the pulsing lagoons, the interior of Angun Lagoon and Pokok Bay do not experience the alternating patterns of nearshore and lagoon water observed in Simpson Lagoon.

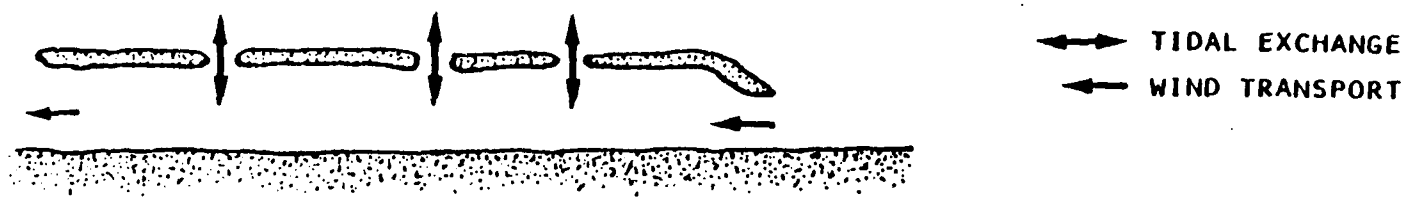
5.3. Limited Exchange Lagoons

The final lagoon type to be discussed has been termed the limited exchange lagoon since only limited throughput of nearshore waters is possible. An example of this type is Beaufort Lagoon (east of Angun Lagoon), actually composed of several small interconnected narrow lagoons with an extensive offshore barrier island chain. The barrier island chain (Icy Reef) has a relatively small number of openings distributed along its length, but several of the openings are quite wide, allowing the possibility of net wind-driven flowthrough of the waters from the longshore current. At the far western end of Beaufort Lagoon is Nuvagapak Lagoon, followed by (moving eastward) Egaksrak Lagoon, Siku Lagoon, Pingokraluk Lagoon, and finally Demarcation Bay. Major entrances include Nuvagapak entrance to the west (which actually consists of two openings: one narrow and quite deep, the other wider but relatively shallow), Egaksrak entrance, Siku entrance, and the main entrance to Demarcation Bay. Other eastern Beaufort Sea lagoons with this configuration include Oruktalik, Jago and Tapkaurak Lagoons.

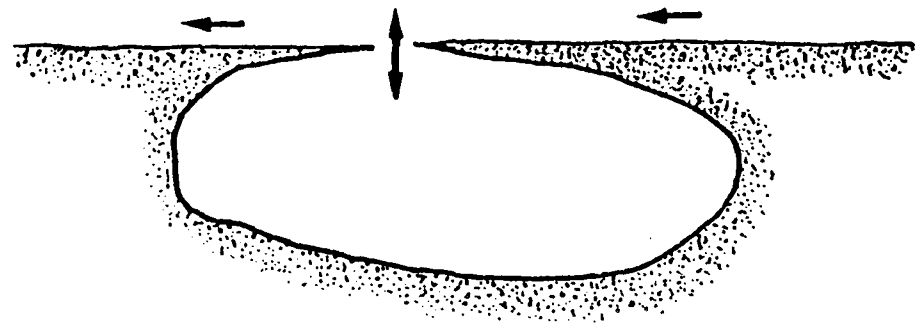
Flowthrough, hence purely advective exchange, is expected to be considerably less than observed for open lagoons. However, considerably more advective exchange is anticipated than for the pulsing lagoons. These limited exchange lagoons encompass over 75 percent of the coastline of the Beaufort Sea east of Barter Island.

The following maps (Figures 11-29) illustrate lagoon and nearshore mean surface currents along the Beaufort Sea coast during a 10 kt NE wind and a 30 kt NW wind.

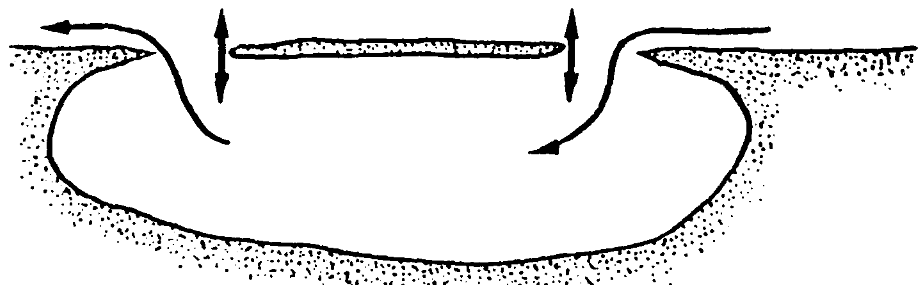
(1 knot = 0.5148 m/s)



TYPE 1. OPEN LAGOON (OPEN TO LONGSHORE CURRENT)



TYPE 2. PULSING LAGOON (CLOSED TO LONGSHORE CURRENT)



TYPE 3. LIMITED EXCHANGE LAGOON (LIMITED LONGSHORE CURRENT EXCHANGE)

FIGURE 9 - BASIC LAGOON TYPES: OPEN, PULSING, AND LIMITED EXCHANGE.

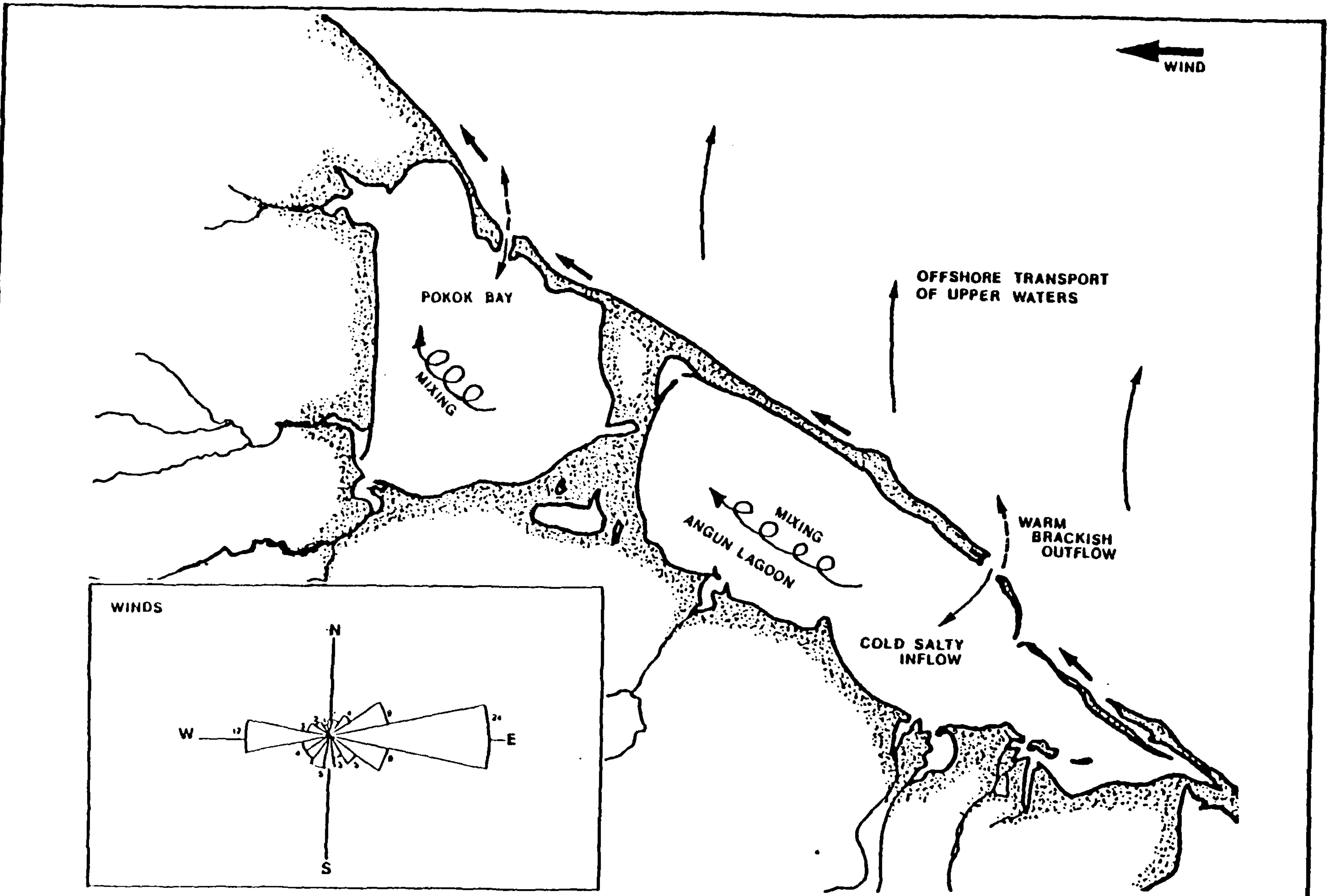


FIGURE 10 - COMBINED WIND AND TIDAL EFFECTS IN A PULSING LAGOON SUCH AS POKOK BAY AND ANGUN LAGOON

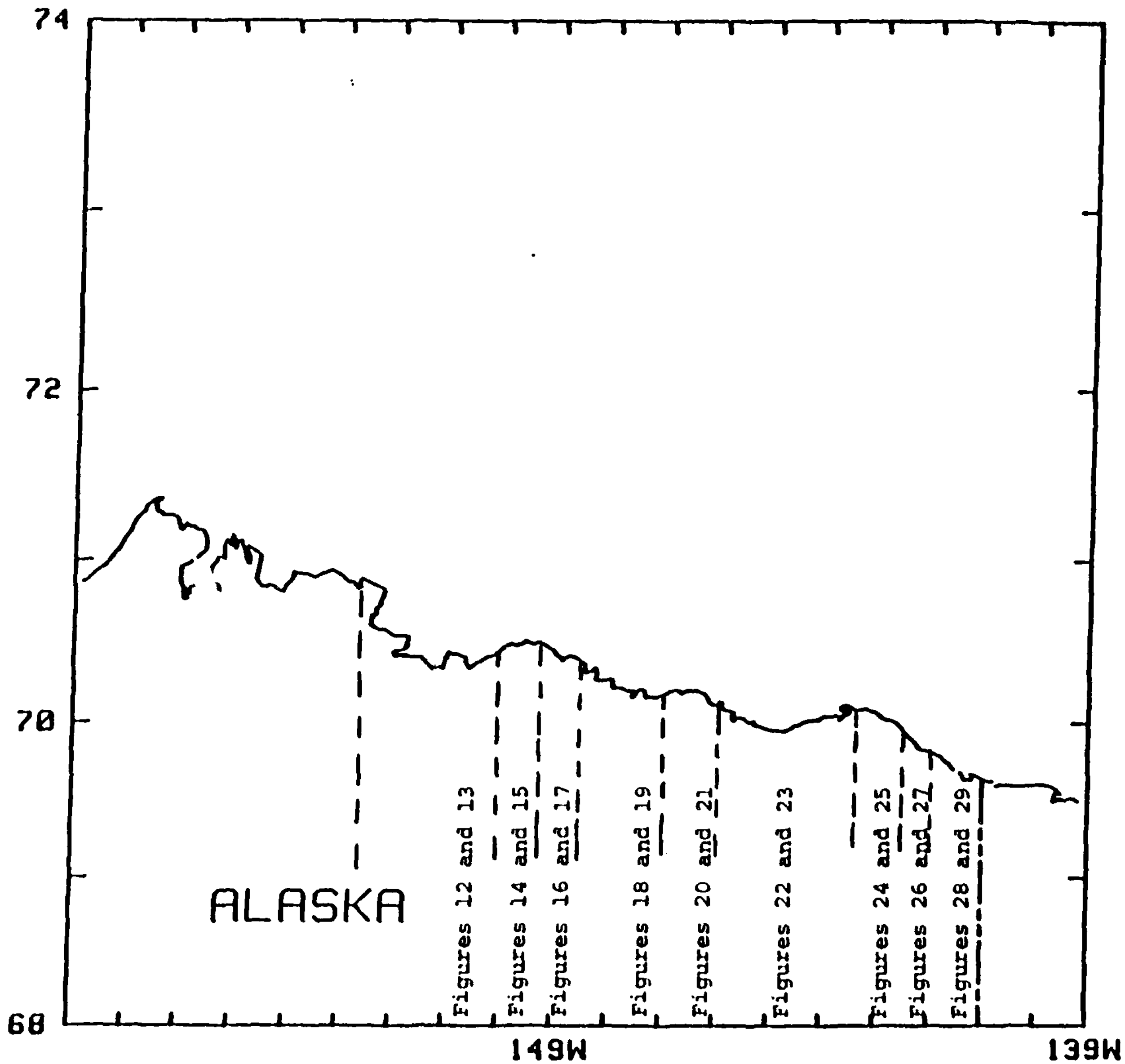


FIGURE 11 - LOCATIONS OF CURRENT ESTIMATE CHARTS FOR LAGOON AND NEARSHORE CIRCULATION.

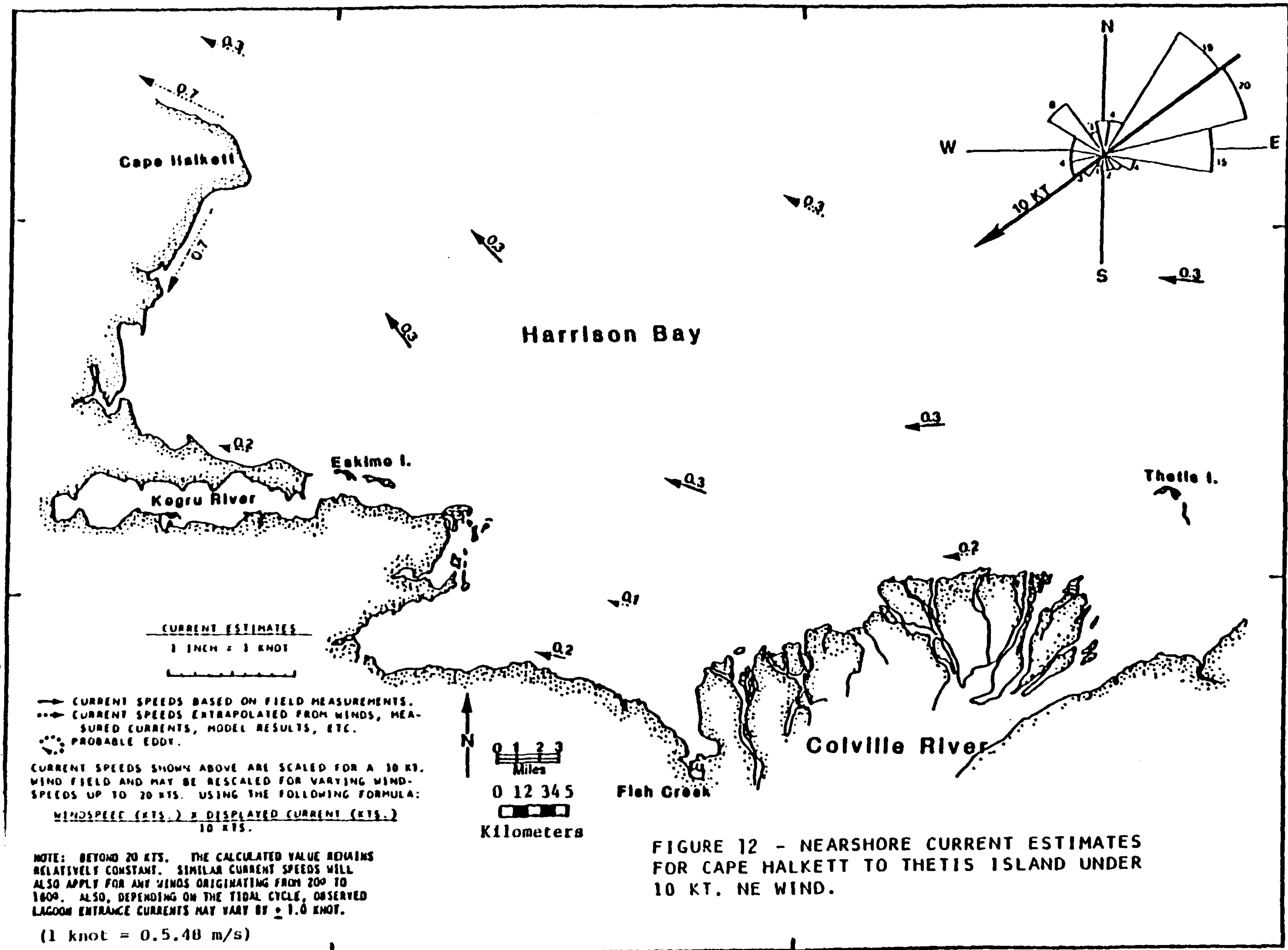


FIGURE 12 - NEARSHORE CURRENT ESTIMATES FOR CAPE HALKETT TO THETIS ISLAND UNDER 10 KT. NE WIND.

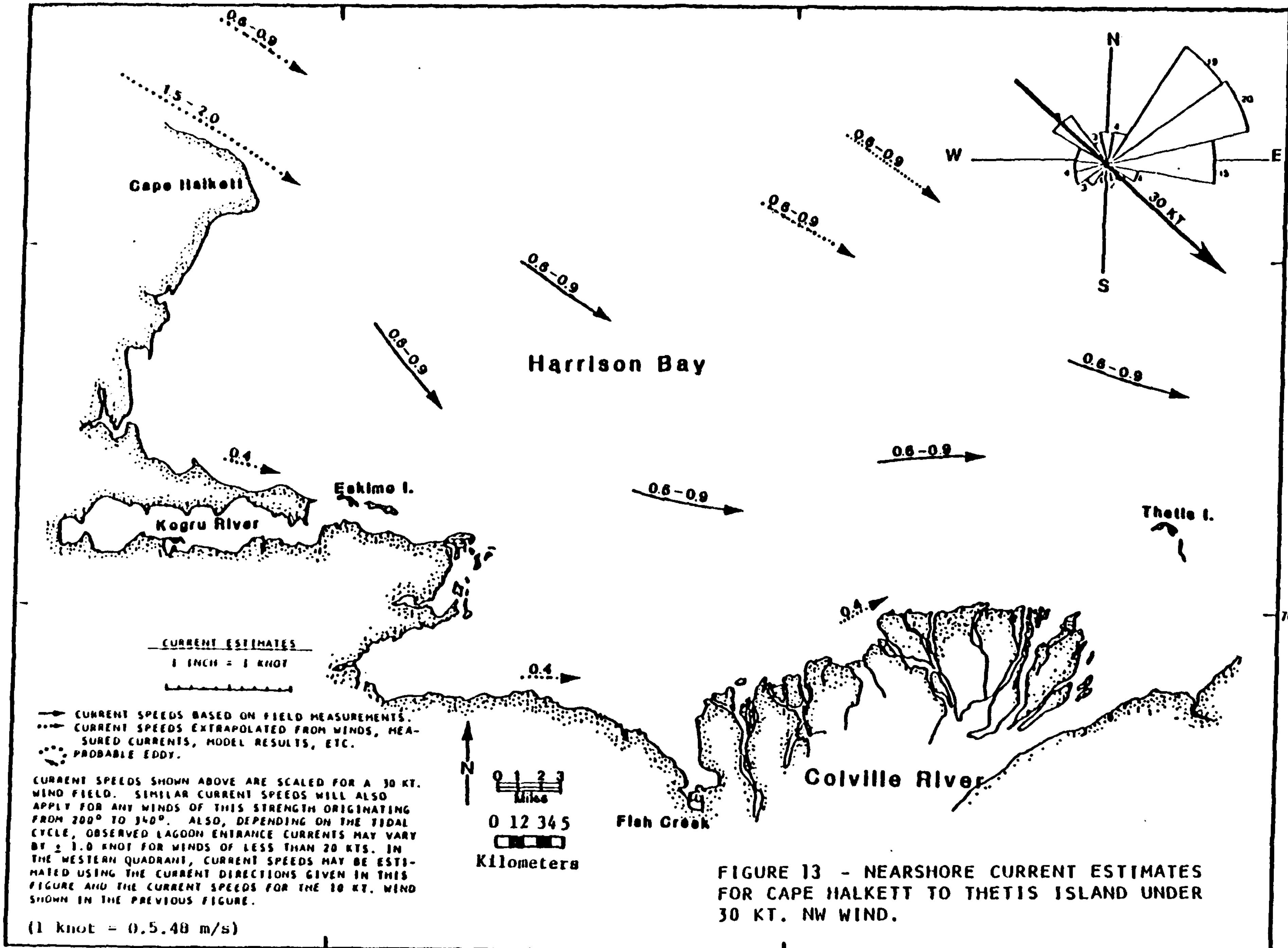


FIGURE 13 - NEARSHORE CURRENT ESTIMATES FOR CAPE HALKETT TO THETIS ISLAND UNDER 30 KT. NW WIND.

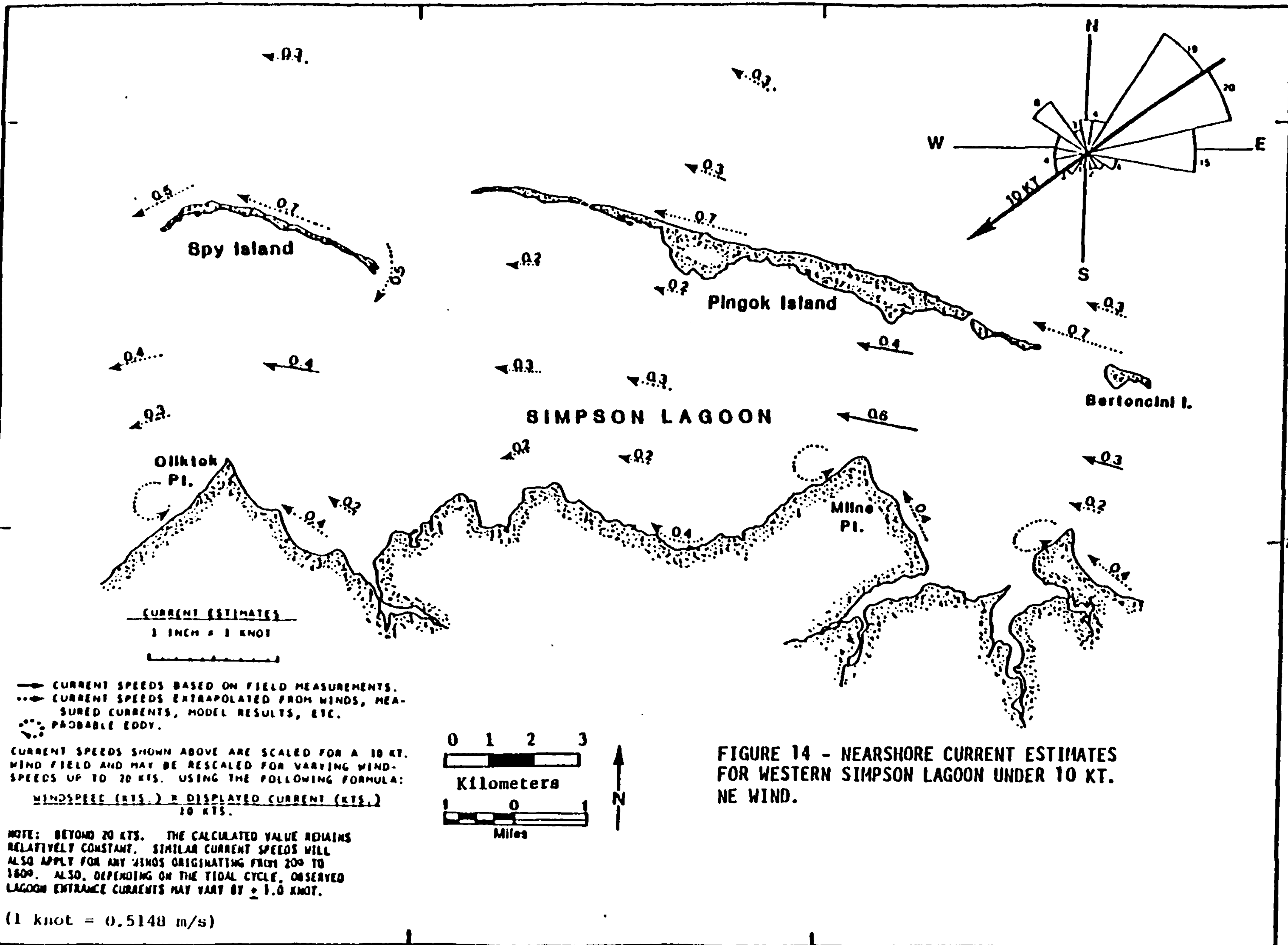
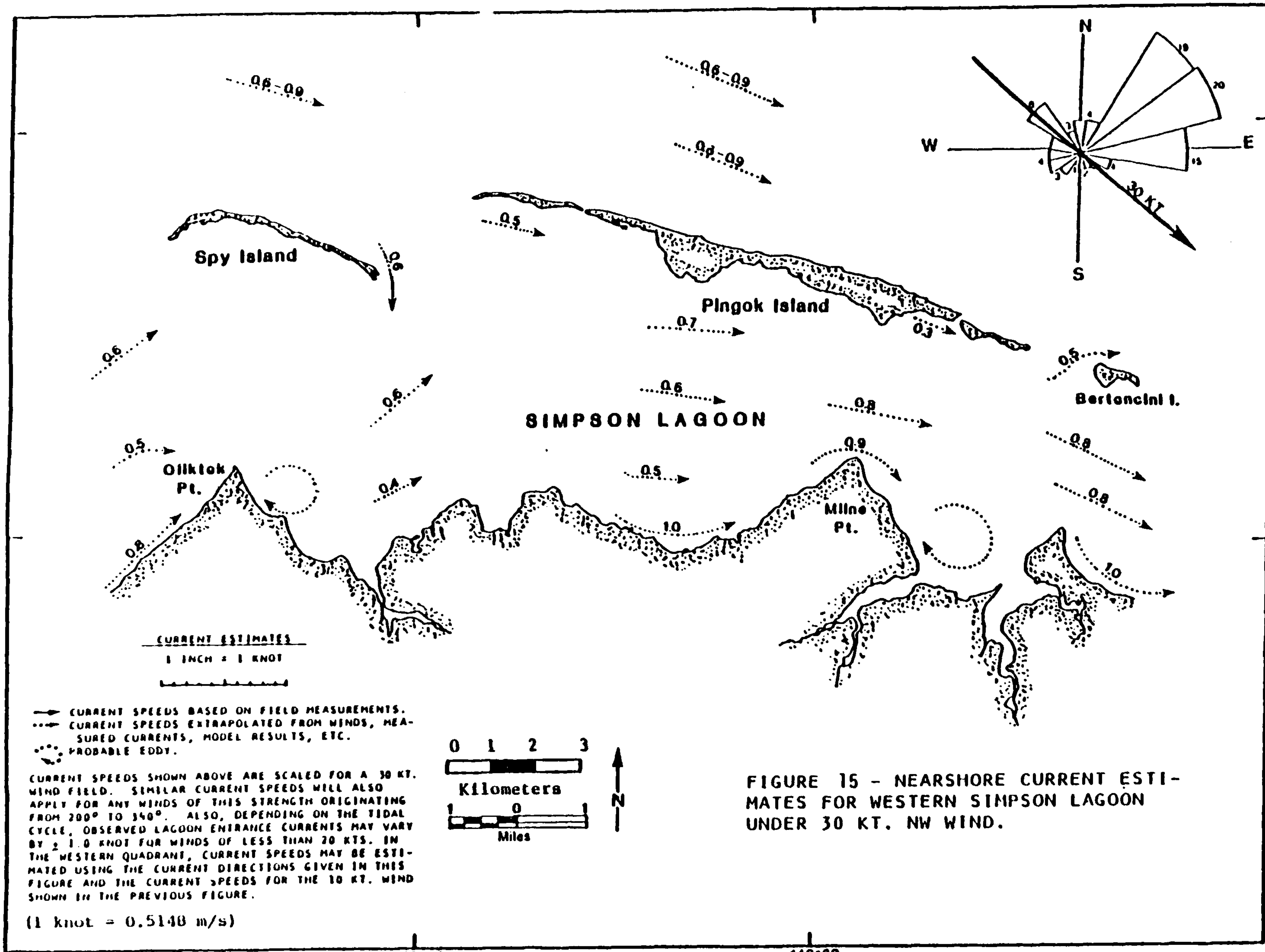


FIGURE 14 - NEARSHORE CURRENT ESTIMATES FOR WESTERN SIMPSON LAGOON UNDER 10 KT. NE WIND.



CURRENT ESTIMATES
1 INCH = 1 KNOT

- CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
- CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
- PROBABLE EDDY.

CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 30 KT. WIND FIELD. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS OF THIS STRENGTH ORIGINATING FROM 280° TO 340°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT FOR WINDS OF LESS THAN 20 KTS. IN THE WESTERN QUADRANT, CURRENT SPEEDS MAY BE ESTIMATED USING THE CURRENT DIRECTIONS GIVEN IN THIS FIGURE AND THE CURRENT SPEEDS FOR THE 10 KT. WIND SHOWN IN THE PREVIOUS FIGURE.

(1 knot = 0.5148 m/s)

FIGURE 15 - NEARSHORE CURRENT ESTIMATES FOR WESTERN SIMPSON LAGOON UNDER 30 KT. NW WIND.

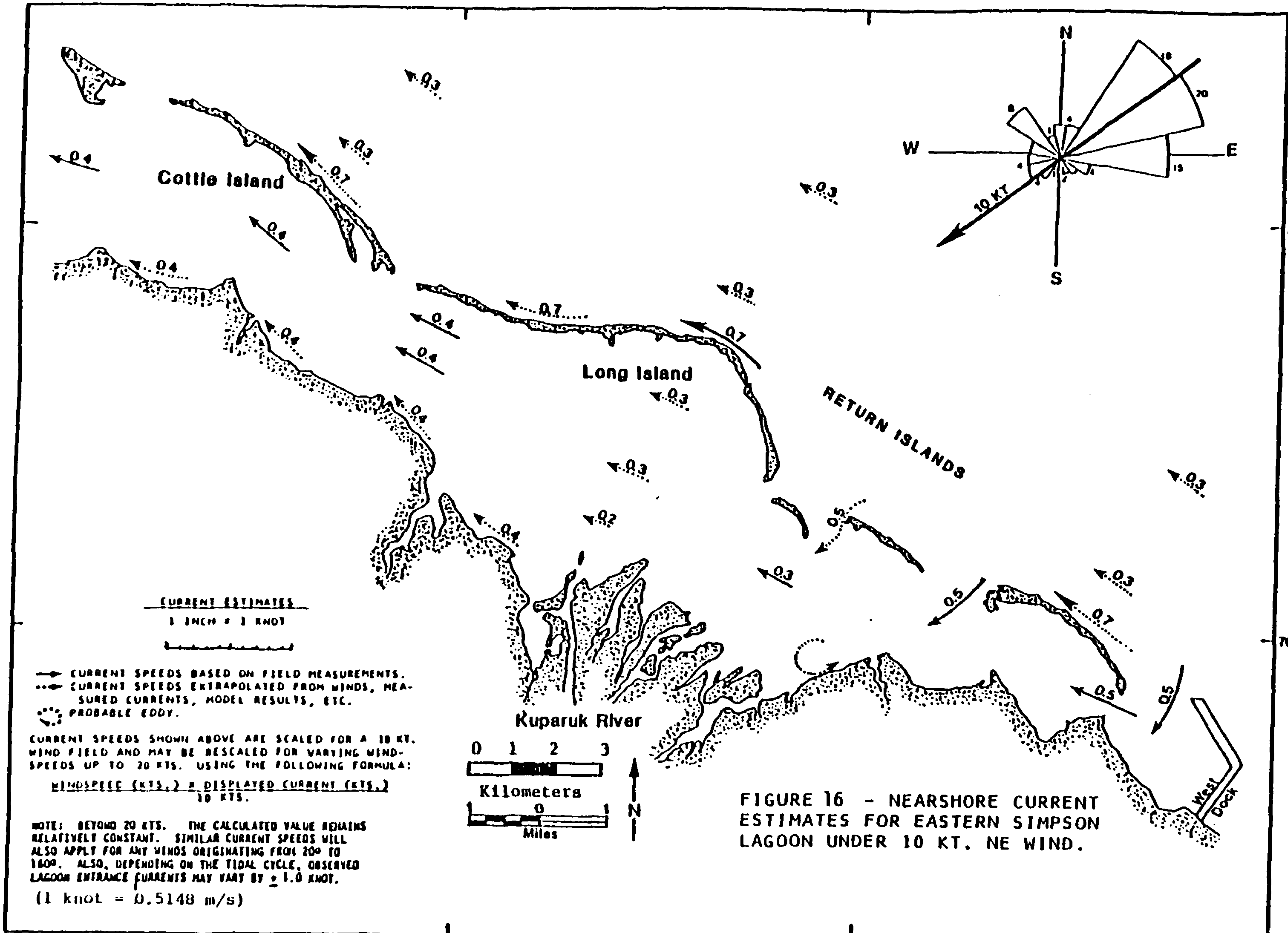


FIGURE 16 - NEARSHORE CURRENT ESTIMATES FOR EASTERN SIMPSON LAGOON UNDER 10 KT. NE WIND.

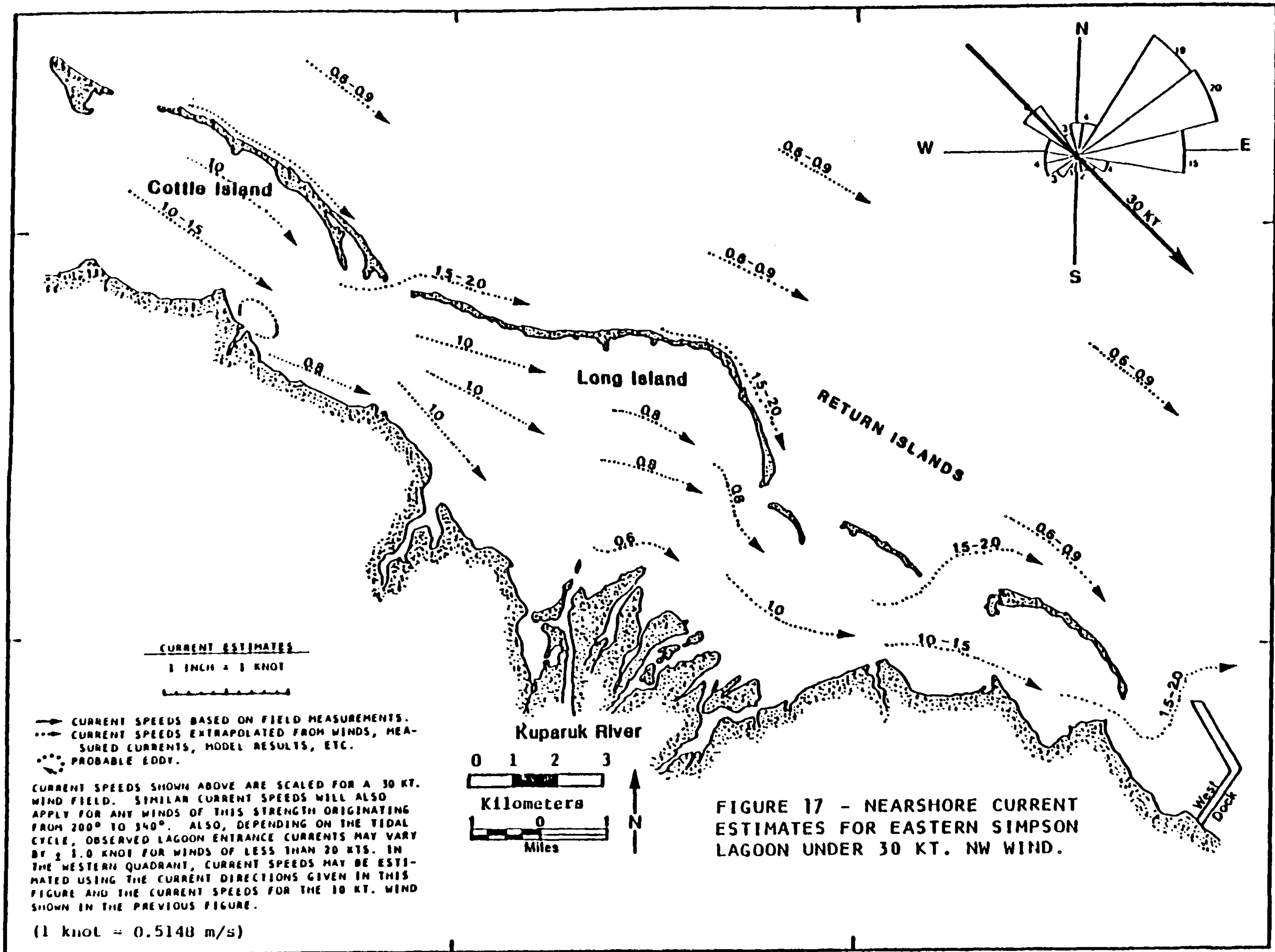


FIGURE 17 - NEARSHORE CURRENT ESTIMATES FOR EASTERN SIMPSON LAGOON UNDER 30 KT. NW WIND.

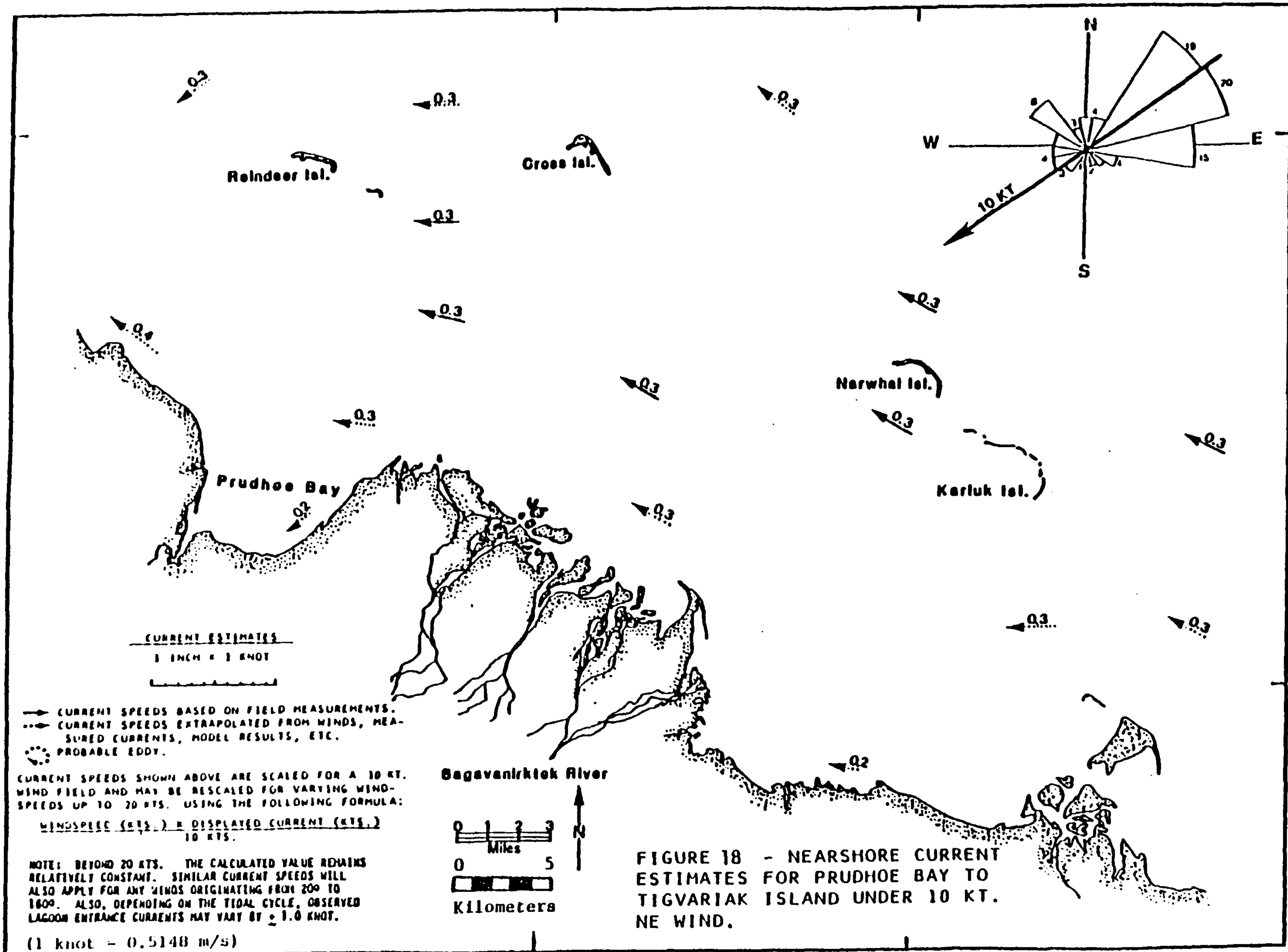


FIGURE 18 - NEARSHORE CURRENT ESTIMATES FOR PRUDHOE BAY TO TIGVARIAK ISLAND UNDER 10 KT. NE WIND.

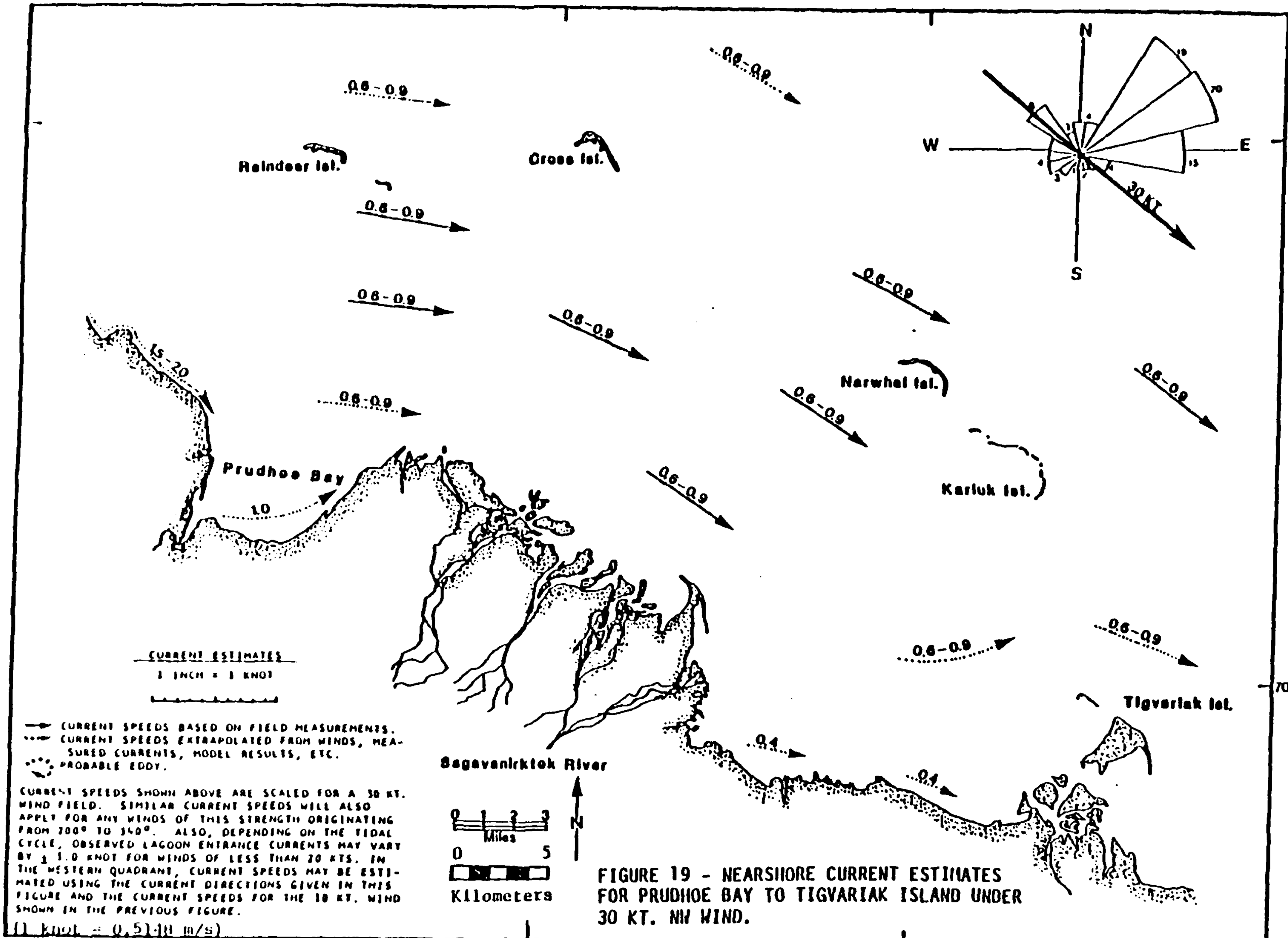


FIGURE 19 - NEARSHORE CURRENT ESTIMATES FOR PRUDHOE BAY TO TIGVARIAK ISLAND UNDER 30 KT. NW WIND.

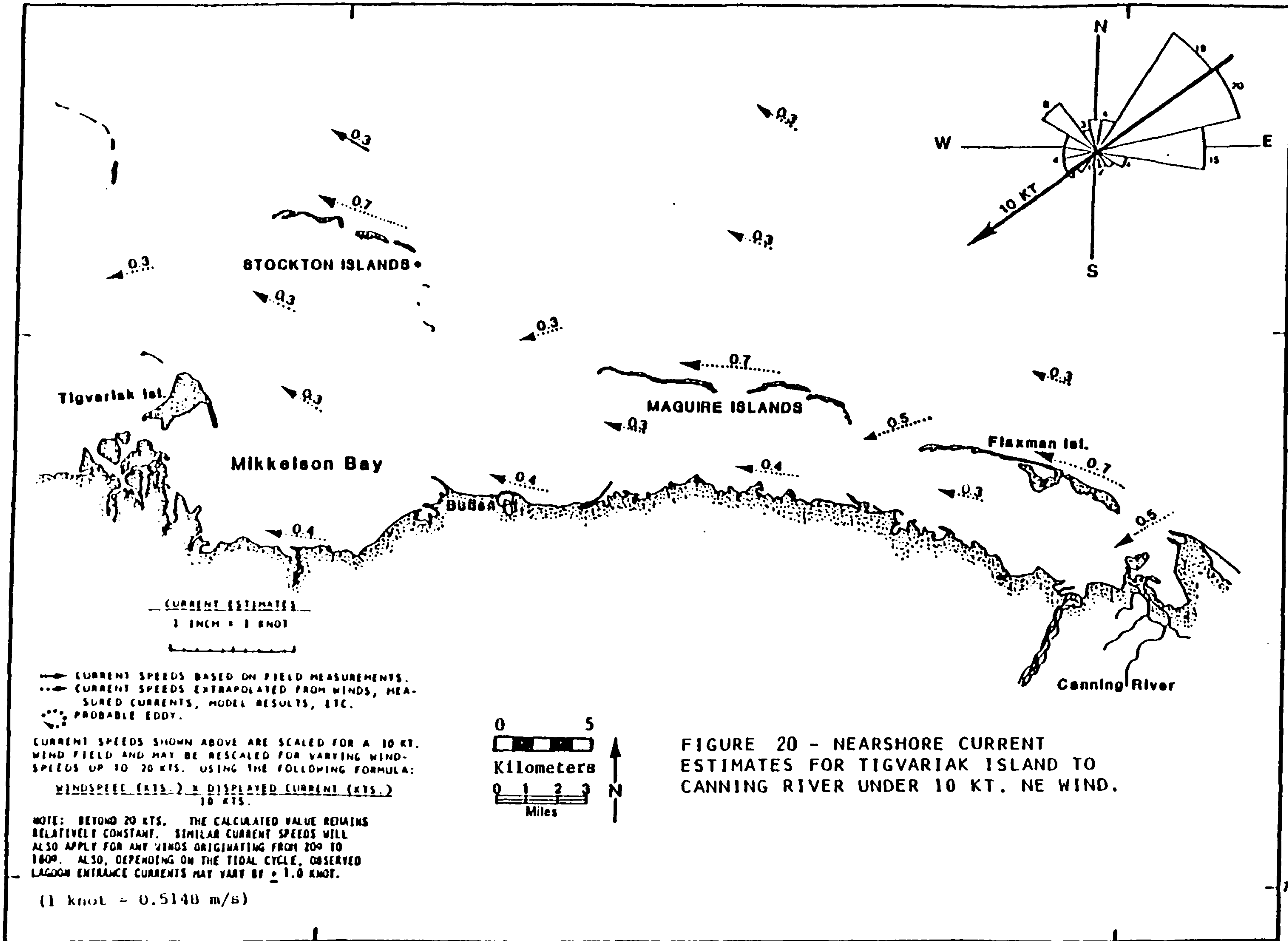


FIGURE 20 - NEARSHORE CURRENT ESTIMATES FOR TIGVARIAK ISLAND TO CANNING RIVER UNDER 10 KT. NE WIND.

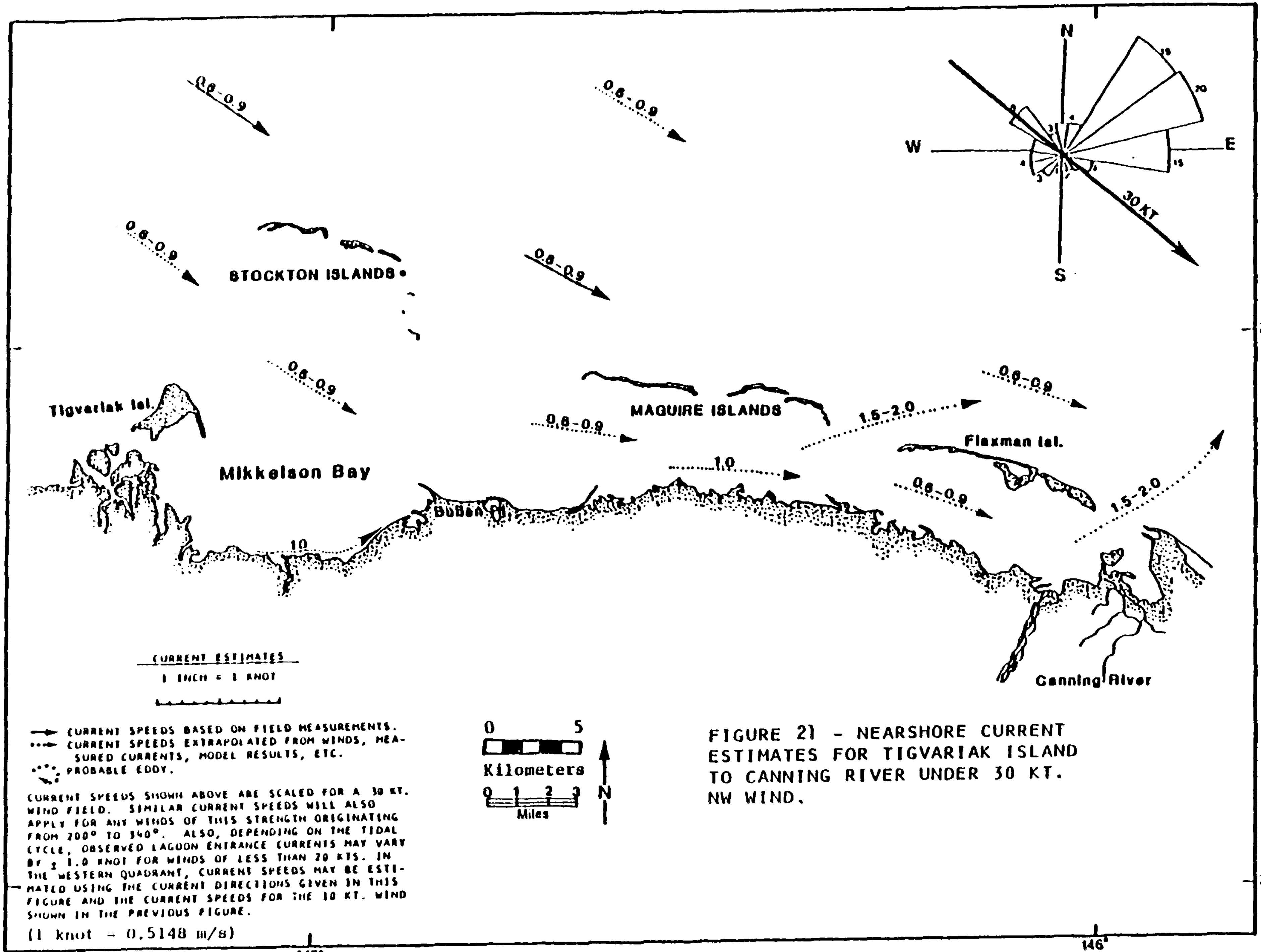


FIGURE 21 - NEARSHORE CURRENT ESTIMATES FOR TIGVARIAK ISLAND TO CANNING RIVER UNDER 30 KT. NW WIND.

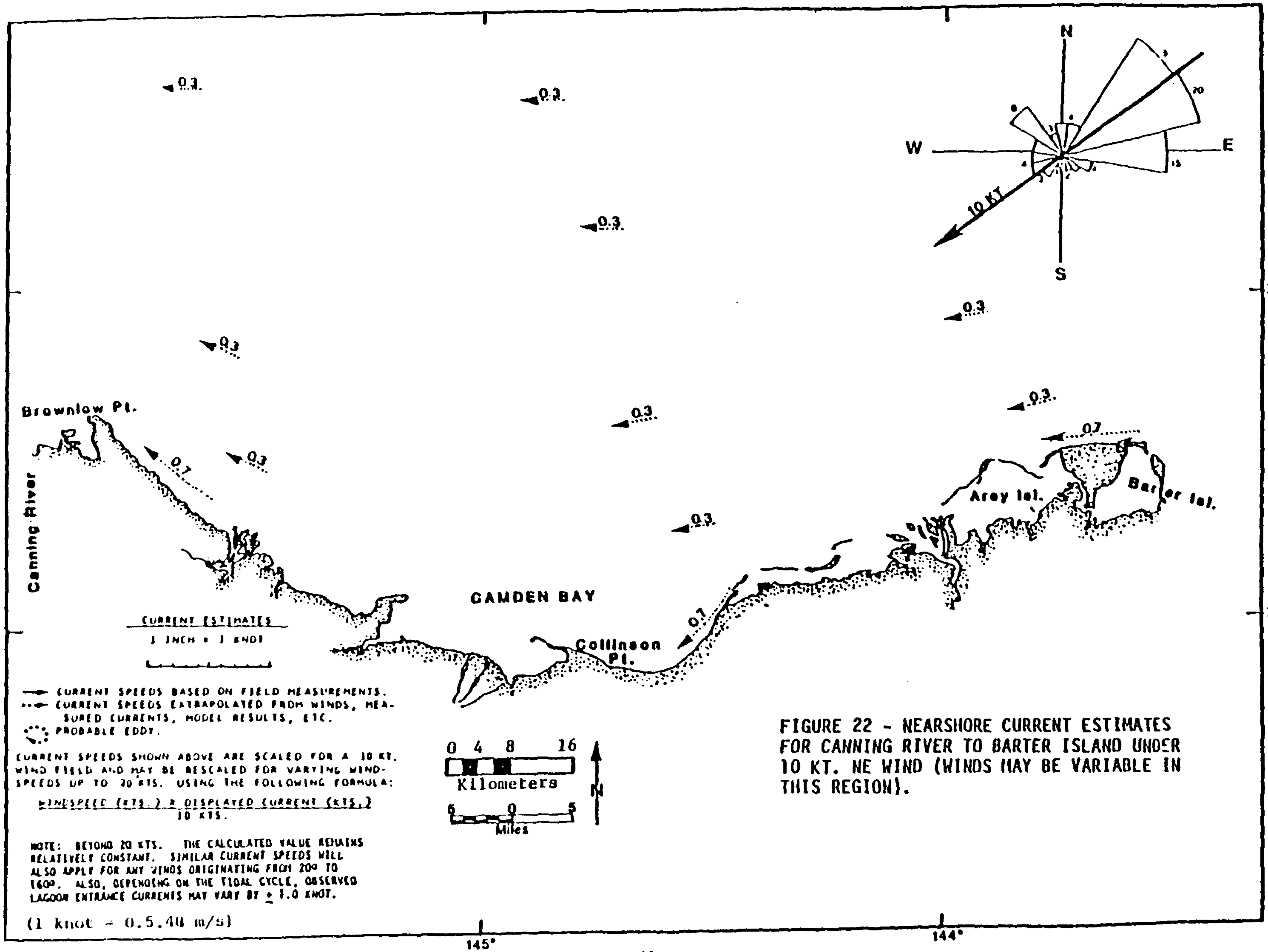


FIGURE 22 - NEARSHORE CURRENT ESTIMATES FOR CANNING RIVER TO BARTER ISLAND UNDER 10 KT. NE WIND (WINDS MAY BE VARIABLE IN THIS REGION).

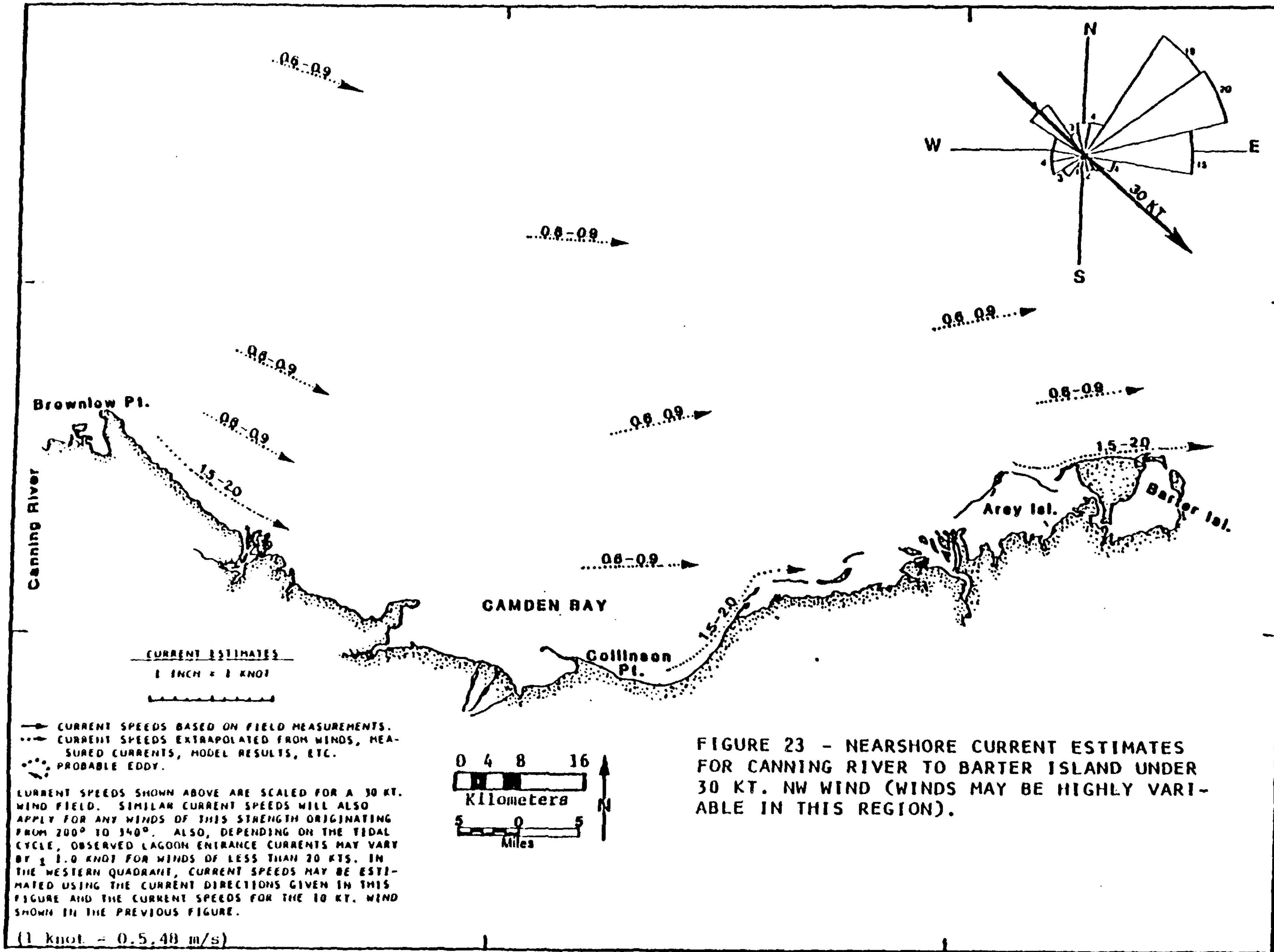


FIGURE 23 - NEARSHORE CURRENT ESTIMATES FOR CANNING RIVER TO BARTER ISLAND UNDER 30 KT. NW WIND (WINDS MAY BE HIGHLY VARIABLE IN THIS REGION).

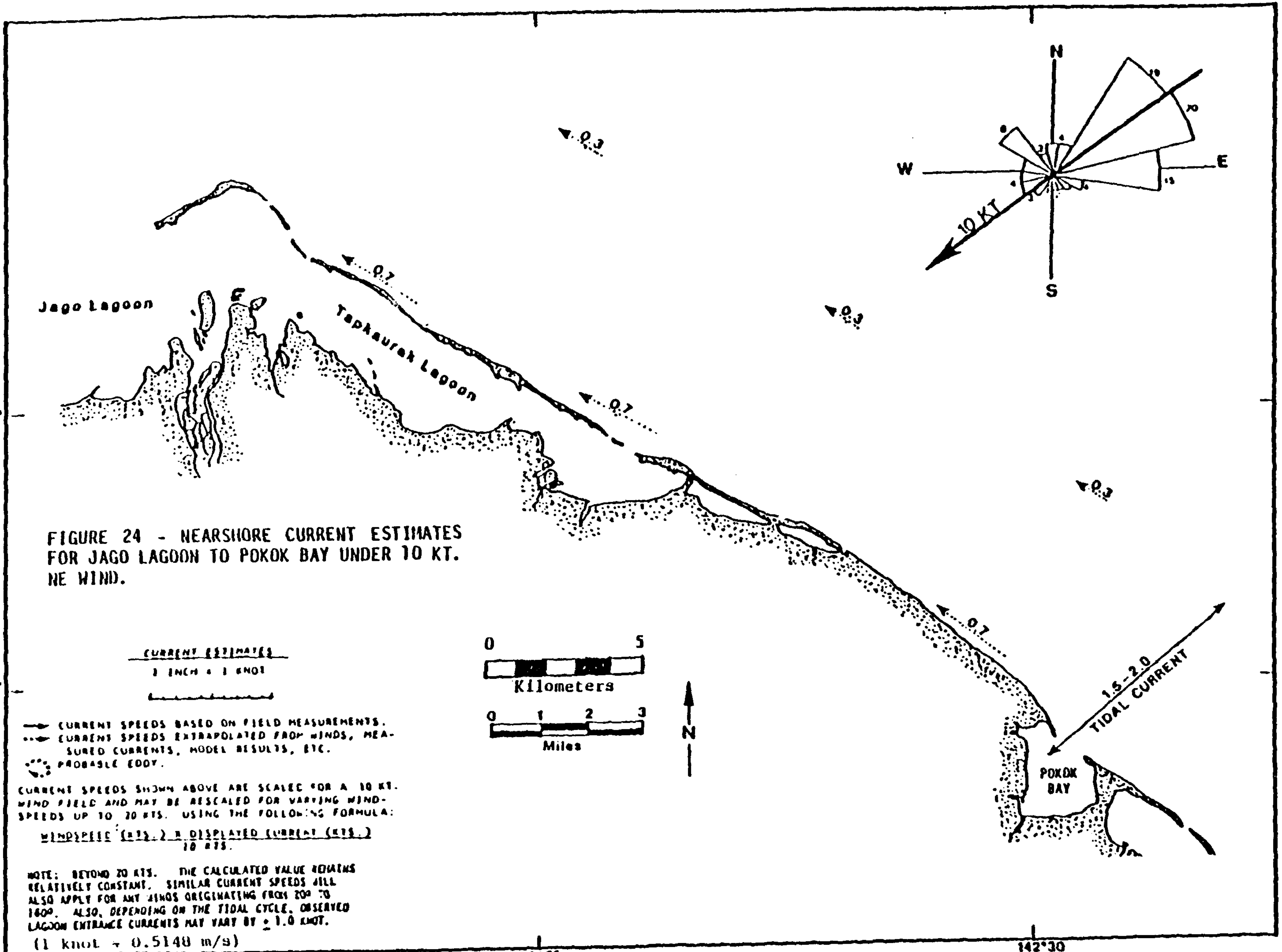


FIGURE 24 - NEARSHORE CURRENT ESTIMATES FOR JAGO LAGOON TO POKOK BAY UNDER 10 KT. NE WIND.

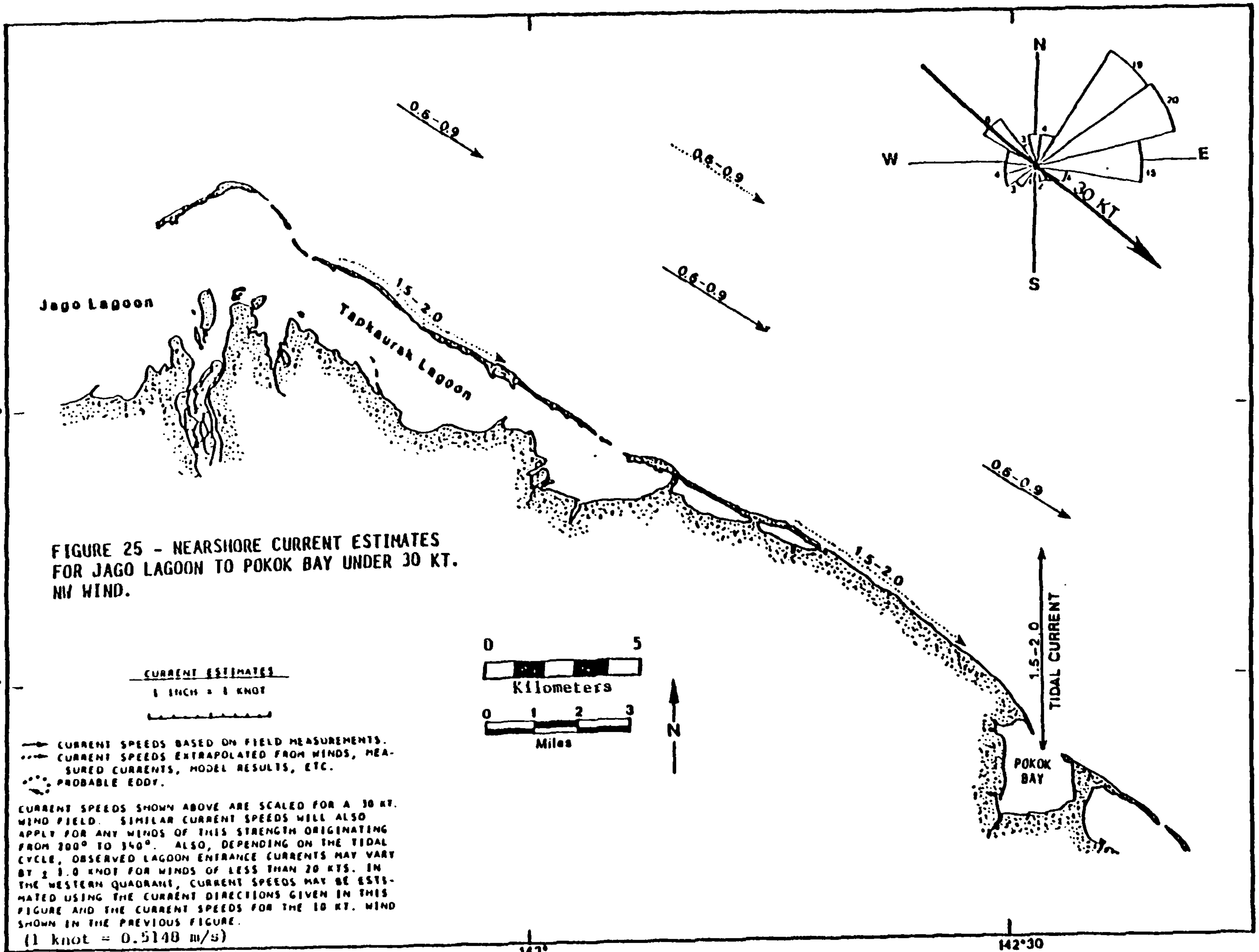


FIGURE 25 - NEARSHORE CURRENT ESTIMATES FOR JAGO LAGOON TO POKOK BAY UNDER 30 KT. NW WIND.

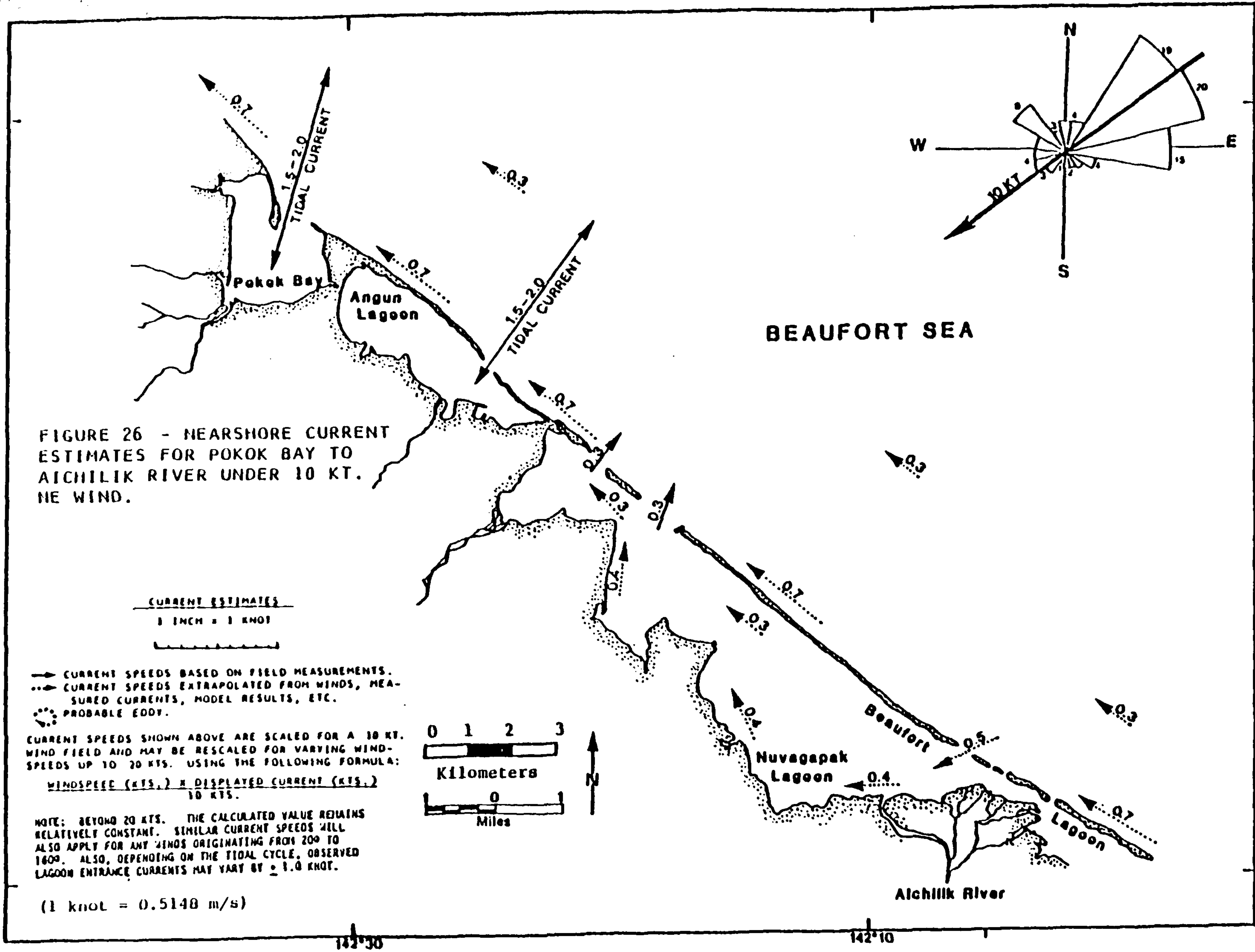


FIGURE 26 - NEARSHORE CURRENT ESTIMATES FOR POKOK BAY TO AICHILIK RIVER UNDER 10 KT. NE WIND.

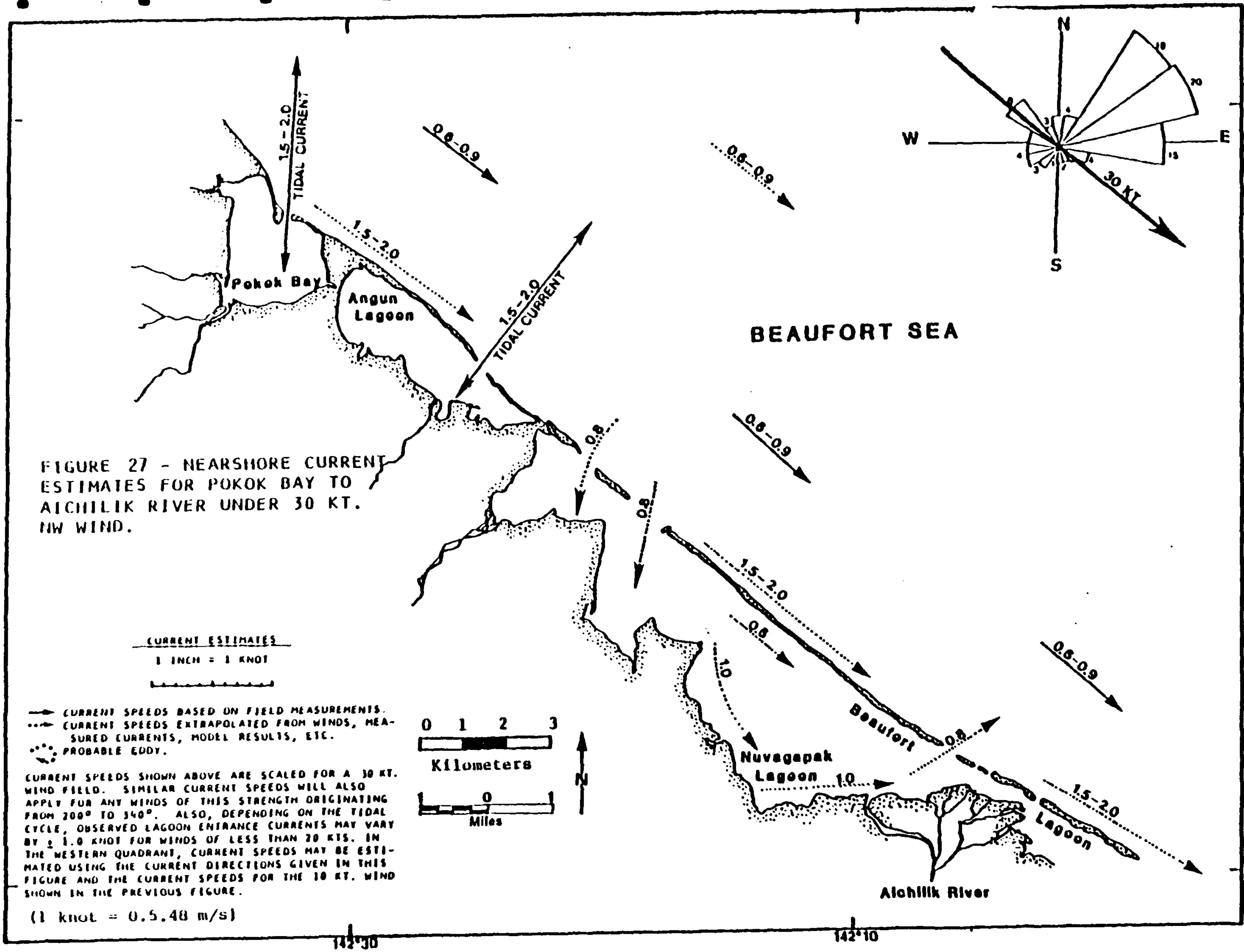


FIGURE 27 - NEARSHORE CURRENT ESTIMATES FOR POKOK BAY TO AICHILIK RIVER UNDER 30 KT. NW WIND.

CURRENT ESTIMATES

1 INCH = 1 KNOT

CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
PROBABLE EDDY.

CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 30 KT. WIND FIELD. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS OF THIS STRENGTH ORIGINATING FROM 200° TO 340°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT FOR WINDS OF LESS THAN 20 KTS. IN THE WESTERN QUADRANT, CURRENT SPEEDS MAY BE ESTIMATED USING THE CURRENT DIRECTIONS GIVEN IN THIS FIGURE AND THE CURRENT SPEEDS FOR THE 10 KT. WIND SHOWN IN THE PREVIOUS FIGURE.

(1 knot = 0.5.48 m/s)

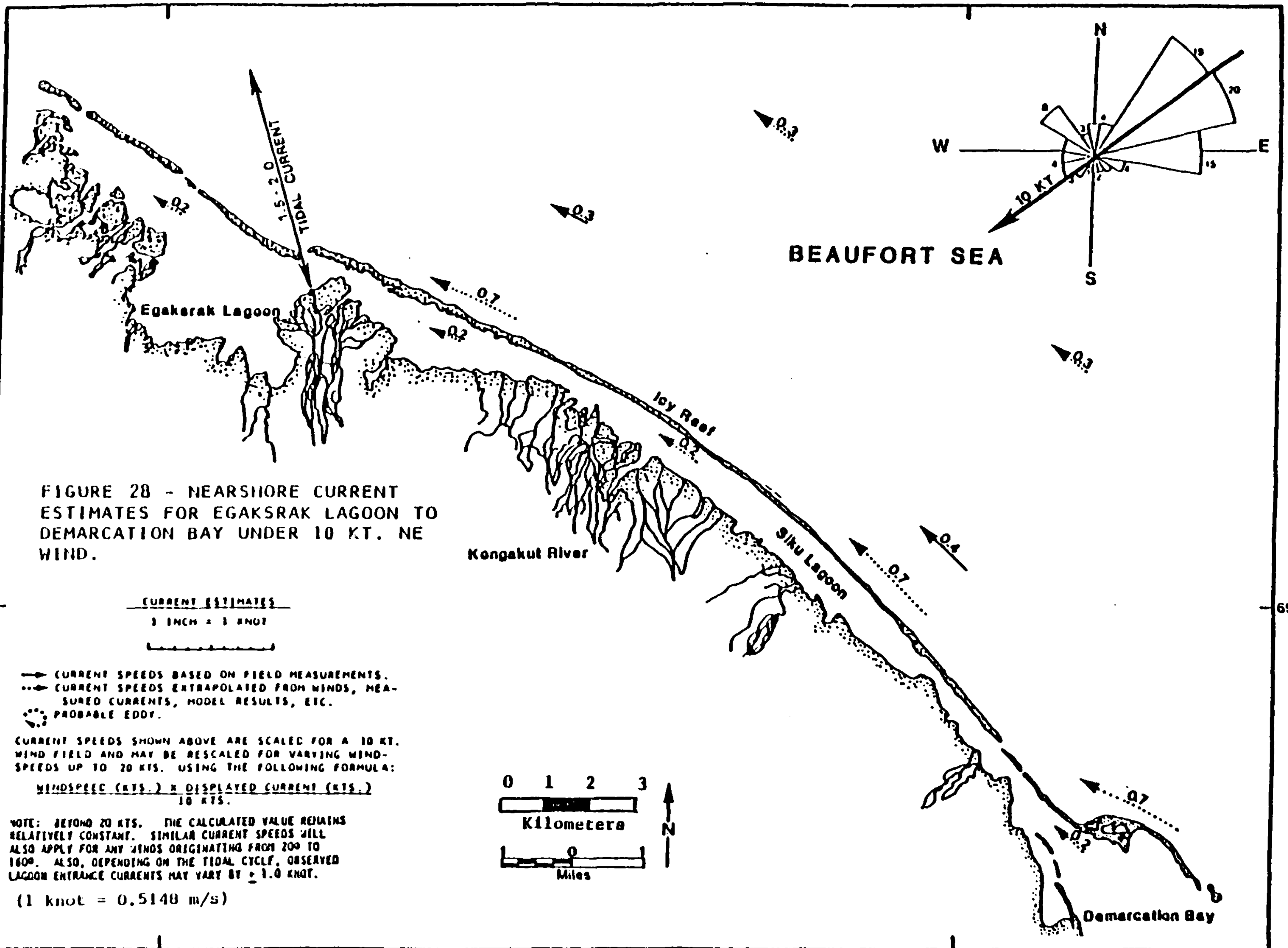


FIGURE 28 - NEARSHORE CURRENT ESTIMATES FOR EGAKSRAK LAGOON TO DEMARCATION BAY UNDER 10 KT. NE WIND.

CURRENT ESTIMATES

1 INCH = 1 KNOT

- CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
- CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
- PROBABLE EDDY.

CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 10 KT. WIND FIELD AND MAY BE RESCALED FOR VARYING WINDSPEEDS UP TO 20 KTS. USING THE FOLLOWING FORMULA:

$$\frac{\text{WINDSPEED (KTS.)} \times \text{DISPLAYED CURRENT (KTS.)}}{\text{10 KTS.}}$$

NOTE: BEYOND 20 KTS. THE CALCULATED VALUE REMAINS RELATIVELY CONSTANT. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS ORIGINATING FROM 20° TO 160°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT.

(1 knot = 0.5148 m/s)

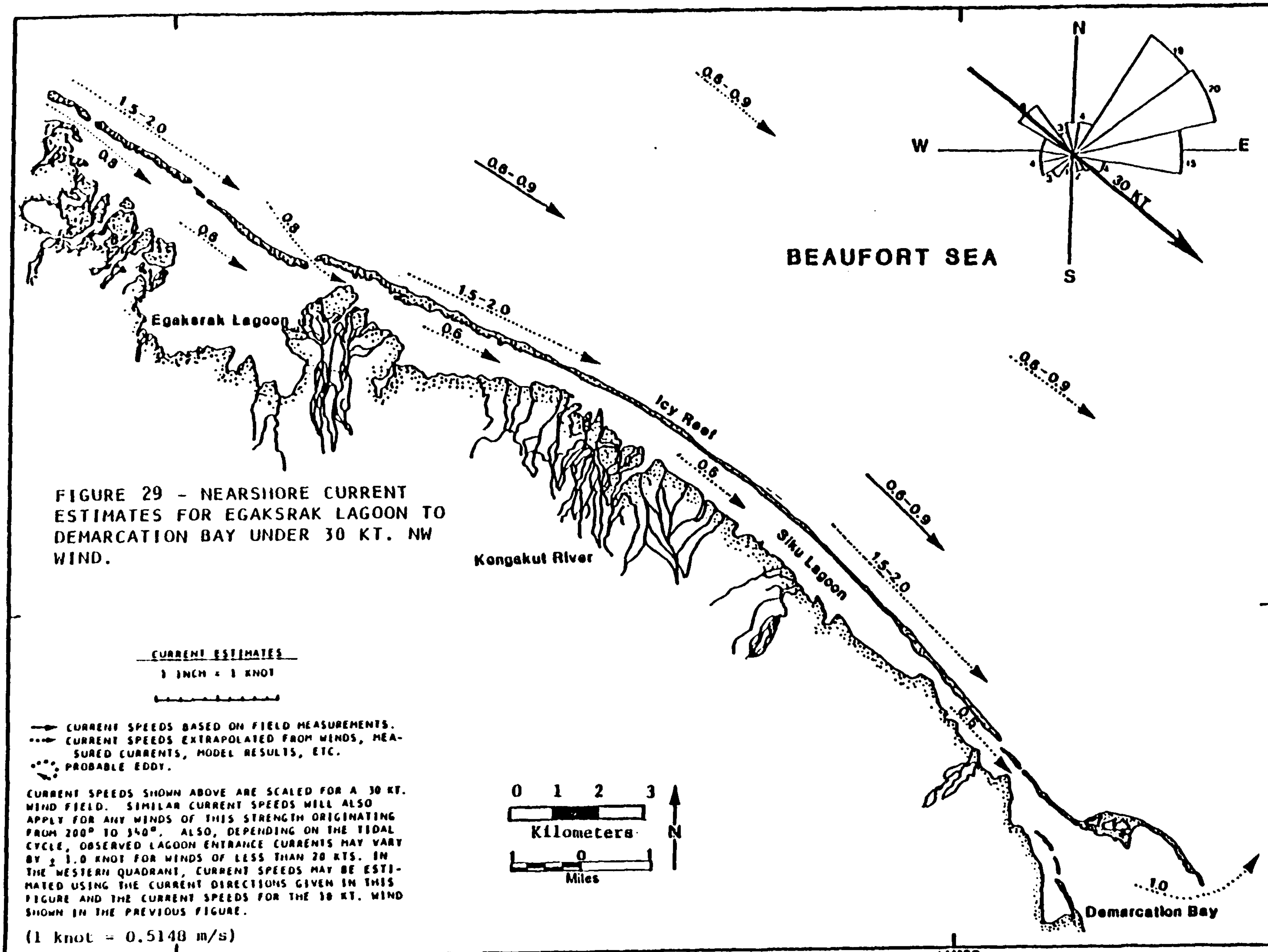


FIGURE 29 - NEARSHORE CURRENT ESTIMATES FOR EGAKSRAK LAGOON TO DEMARCATION BAY UNDER 30 KT. NW WIND.

CURRENT ESTIMATES

1 INCH = 1 KNOT

- CURRENT SPEEDS BASED ON FIELD MEASUREMENTS.
- CURRENT SPEEDS EXTRAPOLATED FROM WINDS, MEASURED CURRENTS, MODEL RESULTS, ETC.
- PROBABLE EDDY.

CURRENT SPEEDS SHOWN ABOVE ARE SCALED FOR A 30 KT. WIND FIELD. SIMILAR CURRENT SPEEDS WILL ALSO APPLY FOR ANY WINDS OF THIS STRENGTH ORIGINATING FROM 200° TO 340°. ALSO, DEPENDING ON THE TIDAL CYCLE, OBSERVED LAGOON ENTRANCE CURRENTS MAY VARY BY ± 1.0 KNOT FOR WINDS OF LESS THAN 20 KTS. IN THE WESTERN QUADRANT, CURRENT SPEEDS MAY BE ESTIMATED USING THE CURRENT DIRECTIONS GIVEN IN THIS FIGURE AND THE CURRENT SPEEDS FOR THE 30 KT. WIND SHOWN IN THE PREVIOUS FIGURE.

(1 knot = 0.5148 m/s)

TIDES

6.0. TIDES

Tides in the northeastern Chukchi and Beaufort Seas are generally quite small and are characterized by a mixed semi-diurnal signal with local maxima from 10-30 cm in elevation. The largest and most studied tidal constituent in the Beaufort Sea is the M2 or lunar tide, with a period of 12.42 hours.

Although tidal data for much of the Beaufort Sea are scarce, the few measurements and accompanying theoretical work which does exist to describe the tidal behavior show the amplitude of the M2 component to be in the range of 5-10 cm (Kowalik and Matthews, 1982). Analysis of the phase of the tidal measurements indicates that the tide appears to approach the shelf from a north or northwesterly direction. Contours of equal M2 tidal heights (Figure 30) indicate that the tidal range increases from west to east along the Chukchi and Beaufort Sea coastlines and begins to decrease slightly again approaching Barter Island (approximately 143 °W). In the Alaskan Beaufort Sea, the maximum measured M2 tidal amplitude was made near Oliktok Point and recorded at 7.6 cm (Kowalik and Matthews, 1982; Wise and Searby, 1977). The actual daily tidal heights, which include the effects of all tidal constituents, can be obtained from standard tidal tables available from the Department of Commerce (various years). These tables allow determination of local tidal high and low water times and can be used to assess the relative magnitude of tidal effects for a particular day.

Tidal ellipses are shown in Figure 31. These ellipses can be used to estimate the maximum expected tidal velocities in a given area of the Beaufort Sea. The major axis of each tidal ellipse depicted in the figure indicates the dominant tidal current direction for a particular geographic region and the average magnitude of the tidal current in that direction. The minor axis indicates the average tidal current magnitude in a direction orthogonal to the major axis of tidal motion. The direction of rotation for each tidal ellipse indicates the temporal procession of tidal current directions as the tidal cycle progresses. For example, if a 2.0 cm/sec easterly current is present at high tide on the central Beaufort shelf, then one

quarter of a tidal cycle later the current vector would be rotated counterclockwise to the north and a smaller tidal current of approximately 1.0 cm/sec in the offshore direction would be observed for the M2 tidal component.

The predominant direction of rotation as indicated in Figure 31 is counterclockwise for the Beaufort Sea. Local regions of clockwise rotation, however, are observed in the northeastern Chukchi Sea and in the Chukchi Sea south of the Lisburne Peninsula.

Figure 31 shows that the maximum velocity of the M2 tidal current diminishes rapidly at the boundary between the Chukchi and Beaufort Sea shelf and the Canadian Basin. This observed phenomenon is due to the depth discontinuity associated with the shelf break. There is also greater than 50% decrease (from > 2.0 cm/s to < 0.8 cm/s) in the maximum coastal M2 tidal velocity from the central to the eastern Beaufort Sea shelf.

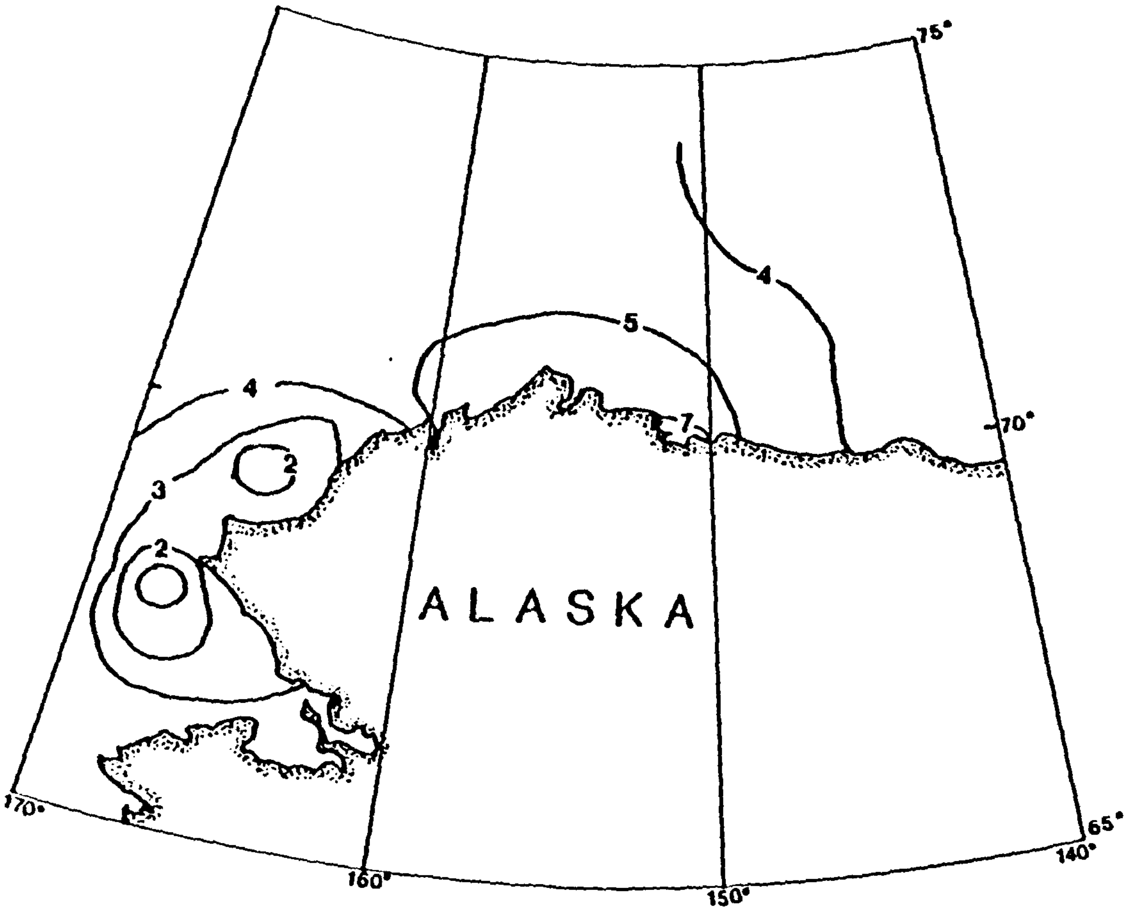


FIGURE 30 - AMPLITUDE OF THE M_2 TIDE IN THE BEAUFORT SEA (FROM KOWALIK AND MATTHEWS, 1982). AMPLITUDE LINE UNITS ARE CM.

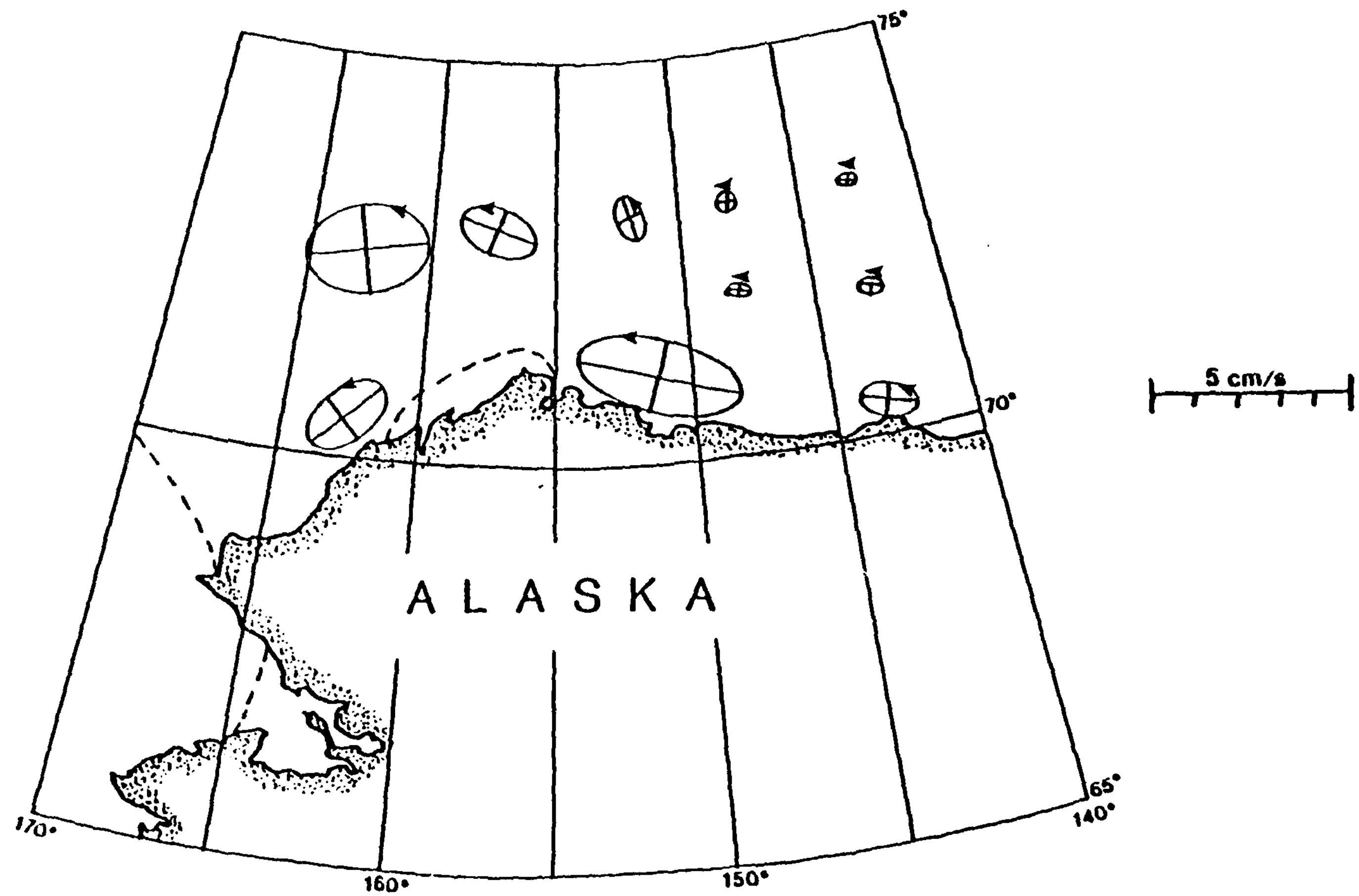


FIGURE 31 - TIDAL ELLIPSES IN THE BEAUFORT SEA; ARROWS DENOTE DIRECTION OF ROTATION ALONG TIDAL ELLIPSE. BROKEN LINES INDICATE BOUNDARIES BETWEEN AREAS WITH DIFFERENT ROTATION (FROM KOWALIK AND MATTHEWS, 1982).

RIVER DISCHARGE

7.0. RIVER DISCHARGE

Arctic coastal river discharges have not been well documented. Only a few of the rivers along the Beaufort Sea coast are gauged, and these are not always regularly monitored. The major rivers entering the Beaufort Sea include the Colville, the Sagavanirktok, the Kuparuk, and the Canning. Hydrographic data for these rivers is given in Table 1. None of these rivers has year-round flow; all cease flowing by late January and begin to flow again in late May and early June. Seawater intrusion into river deltas occurs from mid-autumn through the winter. All rivers have high variability in seasonal annual flow with spring runoff being the major contributor to annual flow volume (Carlson, 1976). Spring and summer discharge of the Colville River and lesser rivers greatly affects the salinity and turbidity of the nearshore Beaufort Sea.

The Colville River is the largest river entering the Beaufort Sea. During spring thaw in June, the Colville River discharges 50 percent of its annual flow. It continues to flow as late as January, with no measurable discharge from then until late April or early May. In the winter months, seawater reaches as far upstream as the Itkillik River.

Annual discharge of the Colville River is 12 km^3 (Schell and Horner, 1981), which is about 73 percent of the total discharge of all rivers between the Colville and Canning Rivers.

River flow from snow melt begins about four weeks prior to breakup of fast ice along the coast. During this time there is a large amount of fresh water forced both under and over the ice in the nearshore region. The extent of the over-ice flow of river water varies greatly from year to year, and is a function of river size and volume of snowmelt. The front of fresh water may move at a rate of 2 to 3 m/s over the ice. Depth of inundation may be between 0.5 and 1.0 m (Reminitz and Bruder, 1972). Measured areas of flooded sea ice are shown in Table 2. Over-ice flood extent from the Colville River is shown in Figure 32 Graphic data are not available for either the Sagavanirktok or Kuparu Rivers.

The flow of the Kuparuk and the Sagavanirktok Rivers have been well documented because of the industrial activity in the region. Maximum and minimum mean daily flows of these rivers are shown in Figures 33-34 .

Table 1

HYDROGRAPHIC DATA FOR MAJOR RIVERS ENTERING THE ALASKAN BEAUFORT SEA

COLVILLE RIVER

Average Annual Flow: 12,000 cubic feet per second (cfs).

Seaward extent of flooded sea ice is 8-18 km; maximum extent of under-ice water plume is 40 km. This is an ungauged river. During spring thaw in June the Colville River discharges 50 percent of its annual volume. Winter flow is assumed to be 0 or negligible. Breakup dates are undocumented, but generally occur the last week of May to the first week of June.

KUPARUK RIVER

Average Annual Flow: 1305 cfs.
Maximum Flow: 82,000 cfs.
Minimum Flow: 10 cfs.

Seaward extent of flooded sea ice is to the barrier islands. The hydrographic regime is shown in Figure 34. River starts flowing from 29 May - 8 June; flow usually ceases between 20-29 September. Sixty to eighty percent of annual runoff occurs in the month of June.

SAGAVANIRKTOK RIVER

Average Annual Flow: 2770 cfs.
Maximum Flow: 20,000 cfs.
Minimum Flow: 10 cfs.

Hydrographic regime is shown in Figure 33. Flow starts 13-22 May; freeze-up occurs between 27 September and 6 October. Sixty to eighty percent of annual runoff occurs in June.

CANNING RIVER

Average Annual Flow: 1125 cfs.

This is an ungauged river. No ice overflow has been mapped; no seasonal discharge information.

(1 cubic foot = 0.028317 cubic meters)

Table 2

AREAL EXTENT OF RIVER OVERFLOW ON SEA ICE IN SPRING

Date	Kuparuk River (km^2)	Sagavanirktok River (km^2)	Colville River (km^2)
21 May 1974*	—	61	15
26 May 1974*	10	151	50
4 June 1974*	3[illegible]	185	61
6 June 1974*	30	40	120
4 June 1975*	101	208	219
9 June 1975*	69	179	276
6 June 1976**	—	100	100

*From Carlson (1977).

**From Barry (1979).

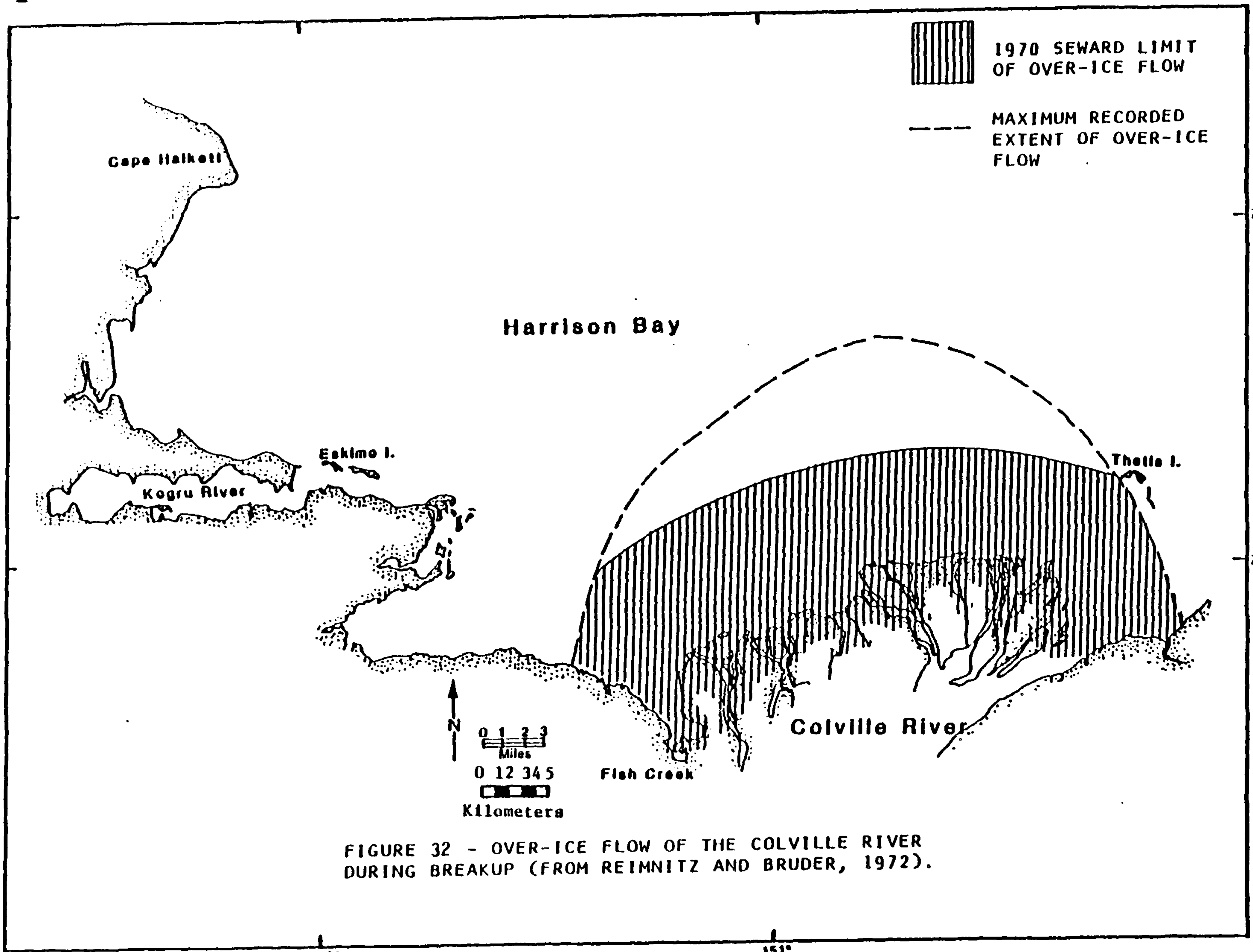


FIGURE 32 - OVER-ICE FLOW OF THE COLVILLE RIVER DURING BREAKUP (FROM REIMNITZ AND BRUDER, 1972).

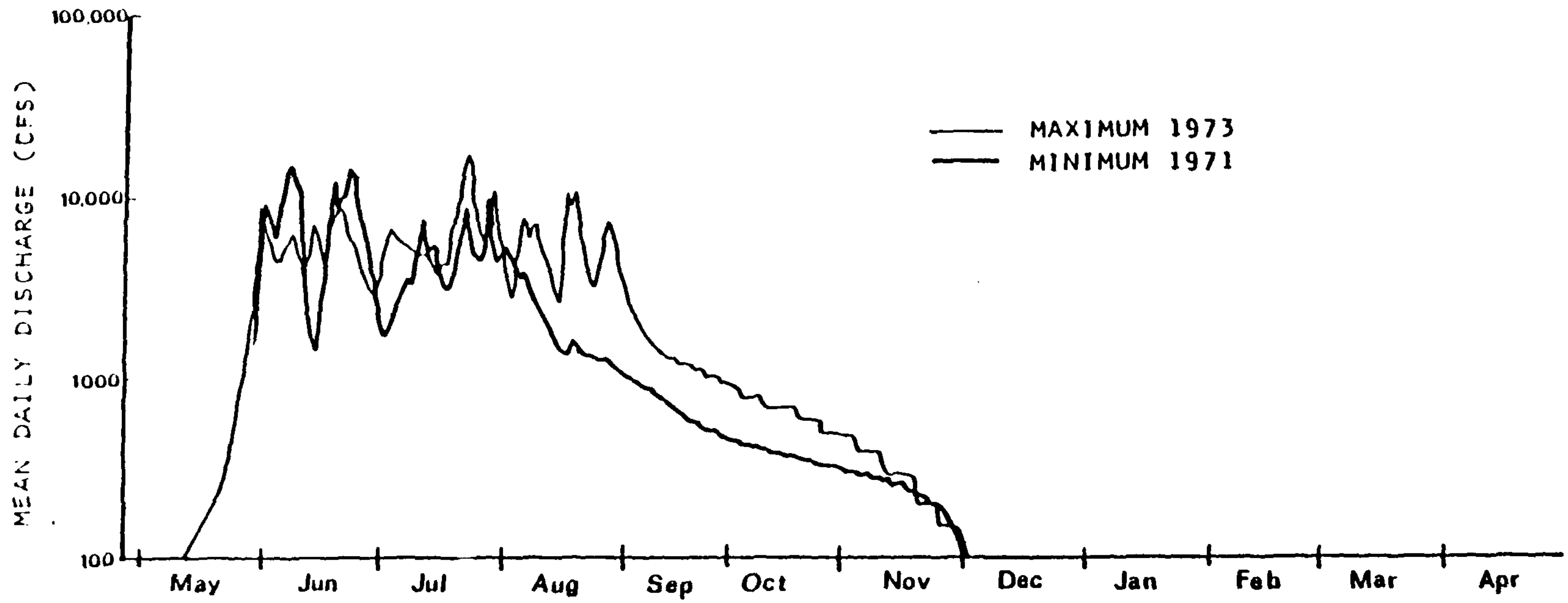


FIGURE 33 - MEAN DAILY DISCHARGE OF THE SAGAVANIRKTOK RIVER: 1971, 1973 (FROM CARLSON, 1977).

(1 cubic foot = 0.028317 cubic meters)

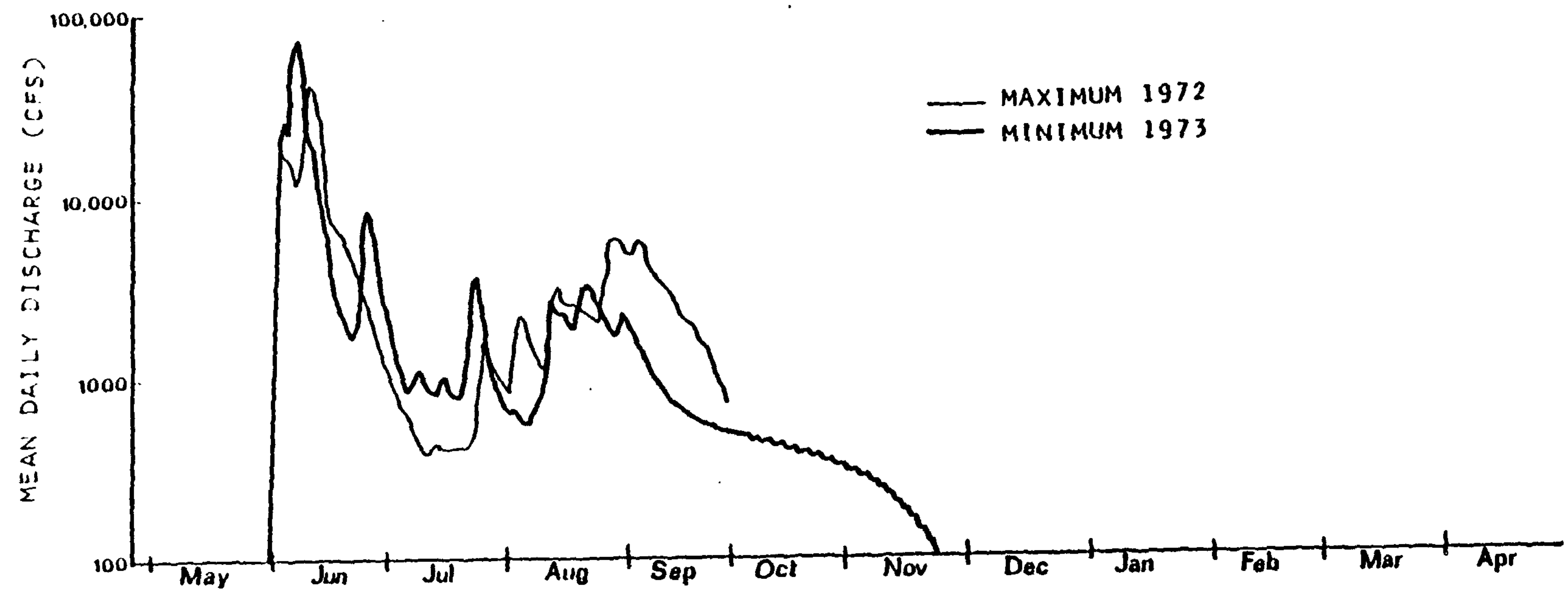


FIGURE 34 - MEAN DAILY DISCHARGE OF THE KUPARUK RIVER: 1972, 1973 (FROM CARLSON, 1977).

(1 cubic foot = 0.028317 cubic meters)

STORM SURGE

8.0. STORM SURGE

The entire Beaufort coast in general experiences relatively small changes in sea level due to astronomical tides; however, meteorologically-induced variations may range from as much as +3.0 m to -0.9 m (Schaeffer, 1966; Matthews, unpublished data). The largest positive storm surges typically occur in the fall when long stretches of open water are common and the winds have become predominantly westerly, driving water onto the shelf. Storm surges may occur with little or no warning. Water may begin to rise before a change occurs in the local wind regime, because of water being driven onto the shelf ahead of the wind. Maximum wave size (up to 3 m) is reached within a few hours of the onset of the storm. Swift easterly currents of 2-3 kts may occur, piling up water on the windward side of the coast.

The best documented storm surge occurred on 13 September 1970 when NW winds of 80 km/hr were recorded at Oliktok Point (Figure 35). Many of the barrier islands off Simpson Lagoon were inundated, and some barges in Prudhoe Bay were lifted out of the water and onto the causeway to which they were secured (Reimnitz and Maurer, 1978). Intervals at which events similar to this occur range from 25-50 years in the central portion of the Beaufort Sea coast. Near Barrow, surges are recorded much more often (Reimnitz and Maurer, 1978).

(1 knot = 0.5148 m/s)

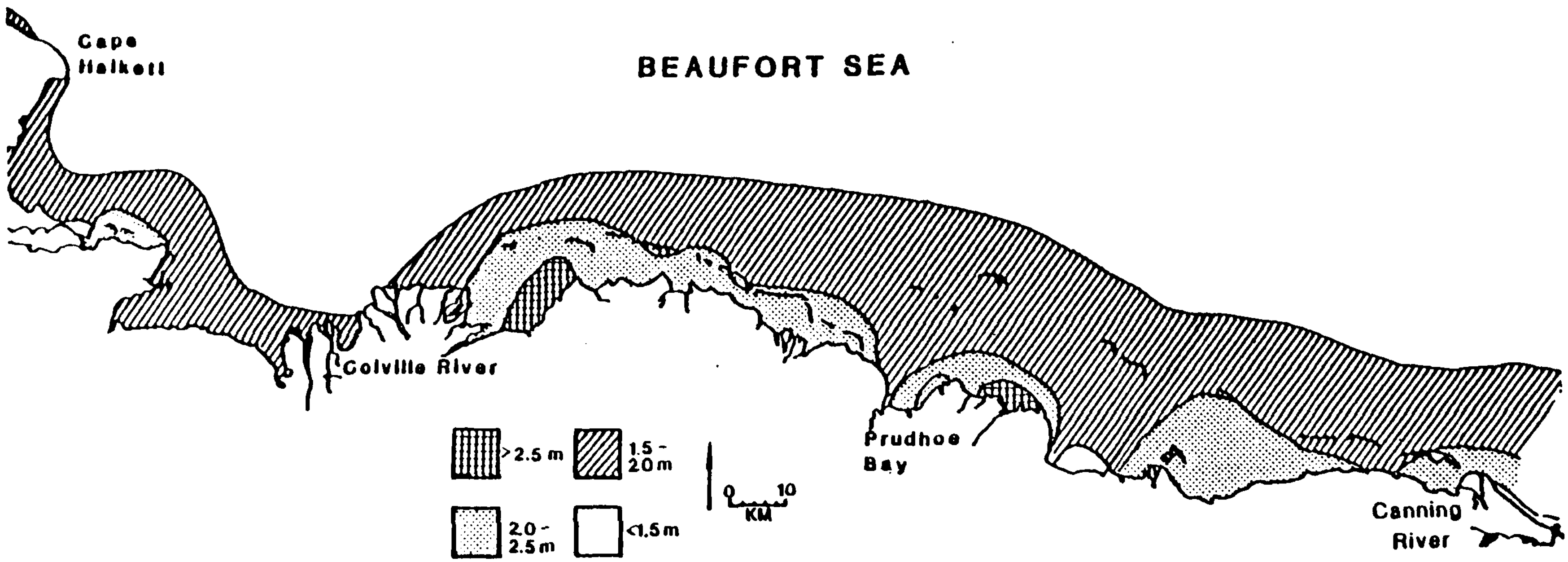


FIGURE 35 - HEIGHT OF 1970 STORM SURGE ABOVE MEAN SEA LEVEL, AS MEASURED FROM THE ELEVATION OF DRIFTWOOD FOUND ON THE MAINLAND AND ON THE ISLANDS. NOTE PILE-UP OF WATER ON THE EAST SIDE OF SHALLOW EMBAYMENTS AND THE LAGOON NEAR THE COLVILLE RIVER (FROM REIMNITZ AND MAURER, 1978).

ICE DRIFT

9.0. ICE DRIFT

The Beaufort Sea shelf is essentially ice covered for all but two to three months of the year. Breakup typically begins in early June which coincides with the initiation of spring river discharge (Section 7.0). As breakup proceeds, a nearshore lead forms from Pt. Barrow to Demarcation Bay which may vary in offshore extent from several kilometers to several hundred kilometers. Open water conditions persist through September and the refreezing process typically begins in early October.

Nearshore ice takes on several forms as the freeze-up process proceeds. Adjacent to the coastline, shorefast ice begins to form and depending on the time of the year may extend out to 70 km from the coastline in the central and western Beaufort. This ice remains relatively motionless throughout the winter months. Offshore of the fast ice is the grounded ice. This is typically ridged and quite thick and stretches along the nearshore at approximately the 20 to 30 m depth contour. This ice is also relatively motionless throughout the winter months. Beyond the grounded ice is the shear zone where the moving ice and the shorefast ice meet.

Few measurements of ice motion exist in or near the shear zone. Beyond the shear zone the ice pack moves at varying speeds and directions under the influence of the wind field. However, mean ice drift similar to the mean wind field exhibits motion to the west. Recent measurement programs have studied this westward drift to determine mean ice speeds and the spatial variability of ice motion.

As part of the Arctic Basin Buoy Program, automatic data buoys were deployed on the pack ice of the Arctic Basin in the years 1979-1982 to monitor large-scale ice movement (Thorndike and Colony, 1979; 1980; Thorndike et al., 1981). Position data from these buoys were transmitted at one-minute intervals and are available in several documents published by the Arctic Basin Buoy Program.

Monthly averages of the buoy motion were determined from these data and are displayed in Figures 36-39. As anticipated, the general drift of the ice is from east to west. Average monthly ice speeds were also determined for one degree latitude bands between 71-74 °N. These values are displayed in Table 3. Monthly averages range from a low of 3 cm/s to a high of 20 cm/s based on the buoy drift data. The peak in the speed of ice drift occurs in the fall, with the lowest ice drift speeds found in late winter and early spring.

All data analyzed for this section were for buoys deployed in the Beaufort Sea between 70-76 °N and 150-170 °W.

Table 3

AVERAGE MONTHLY ICE DRIFT SPEEDS (cm/s) VS. LATITUDE

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
71 - 72°N				3	6	12	14	13	13			
72 - 73°N				5	7	8	11	7	7	9	9	11
73 - 74°N	12	5	4	4	6	6	8	10	20	13	13	9
Monthly Mean	12	5	4	4	6	8	11	10	13	11	11	10

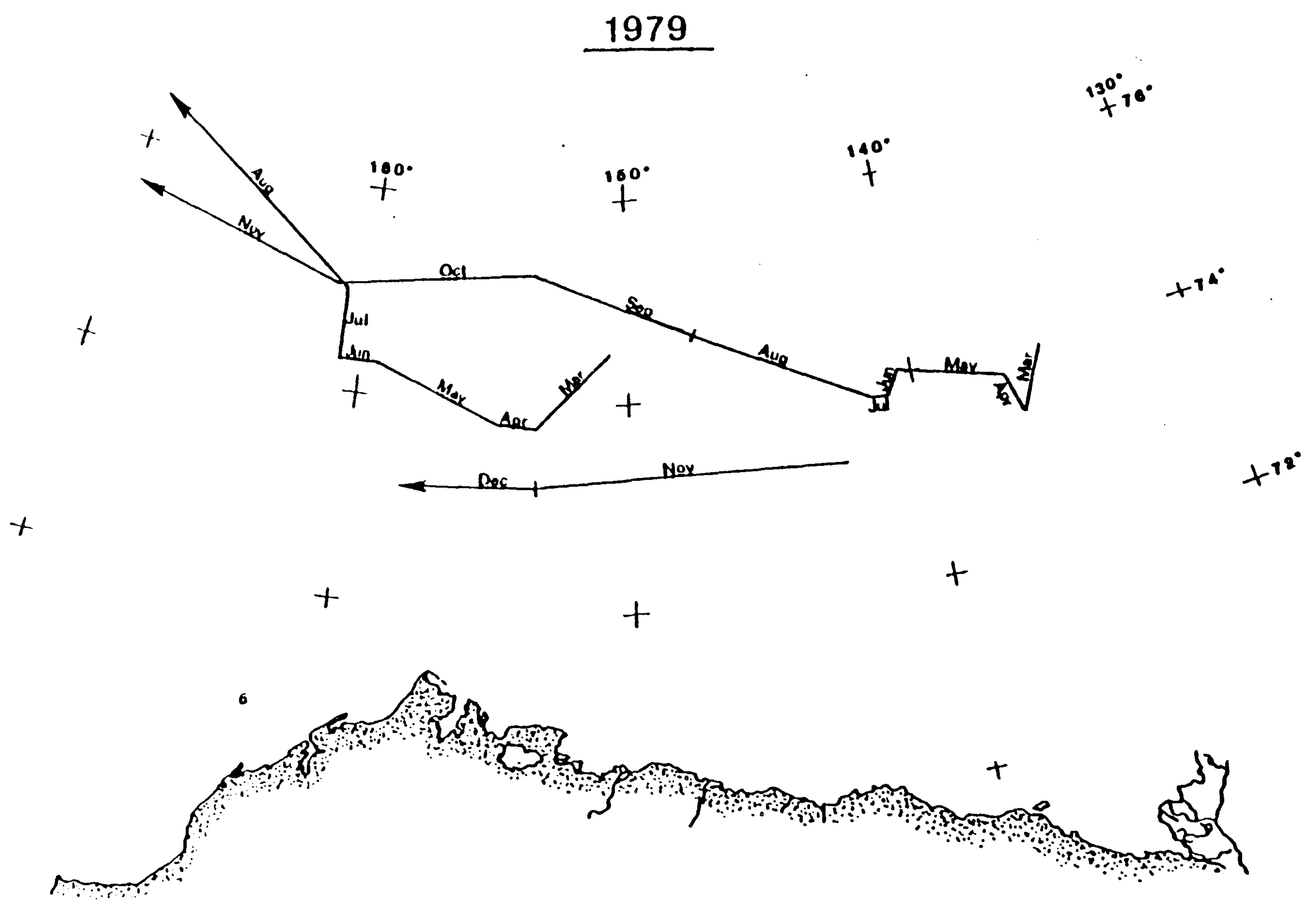


FIGURE 36 - TRACK OF ICE DRIFTER BUOYS OFF THE ALASKAN COAST IN 1979.

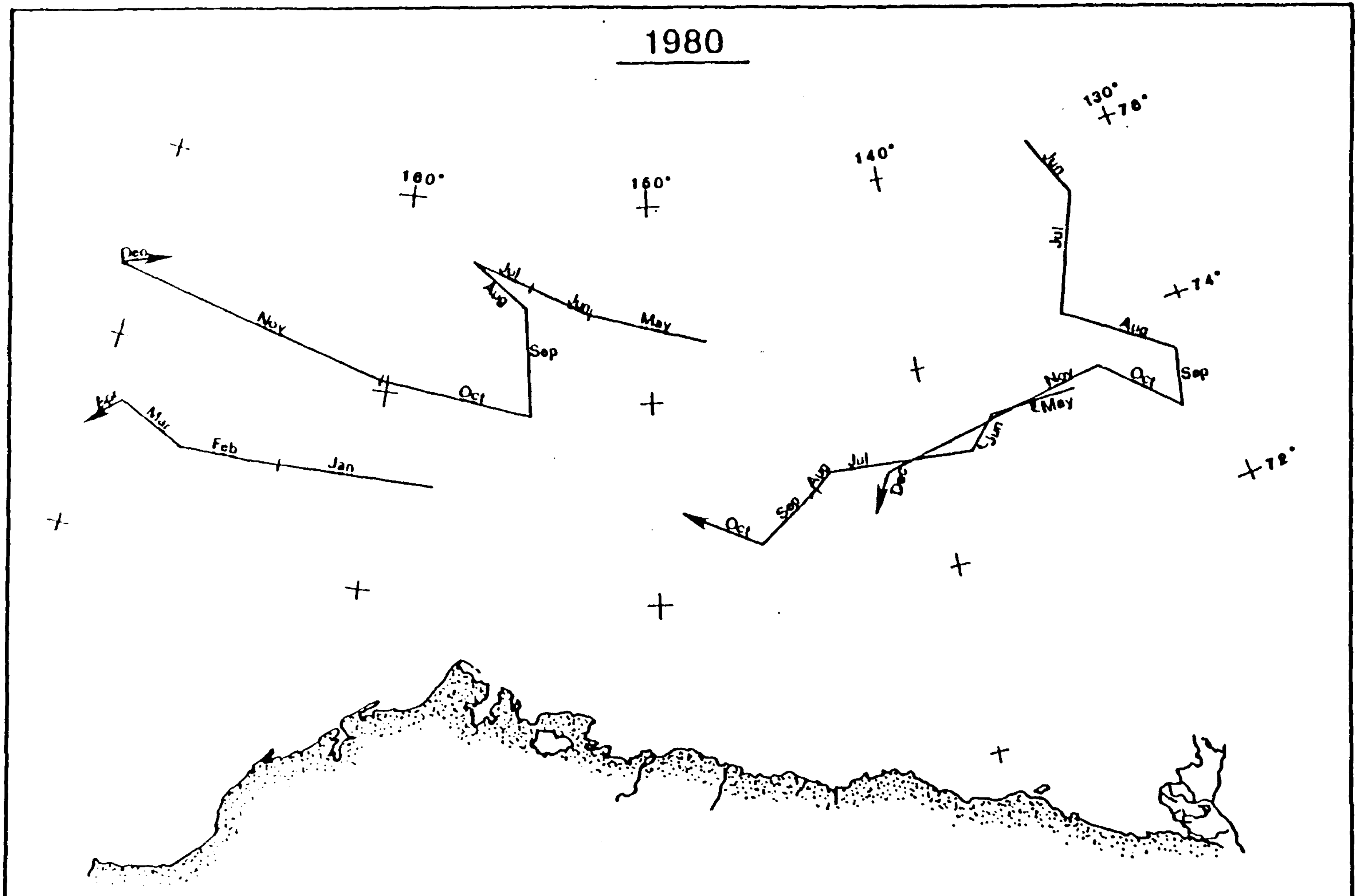


FIGURE 37 - TRACK OF ICE DRIFTER BUOYS OFF THE ALASKAN COAST IN 1980.

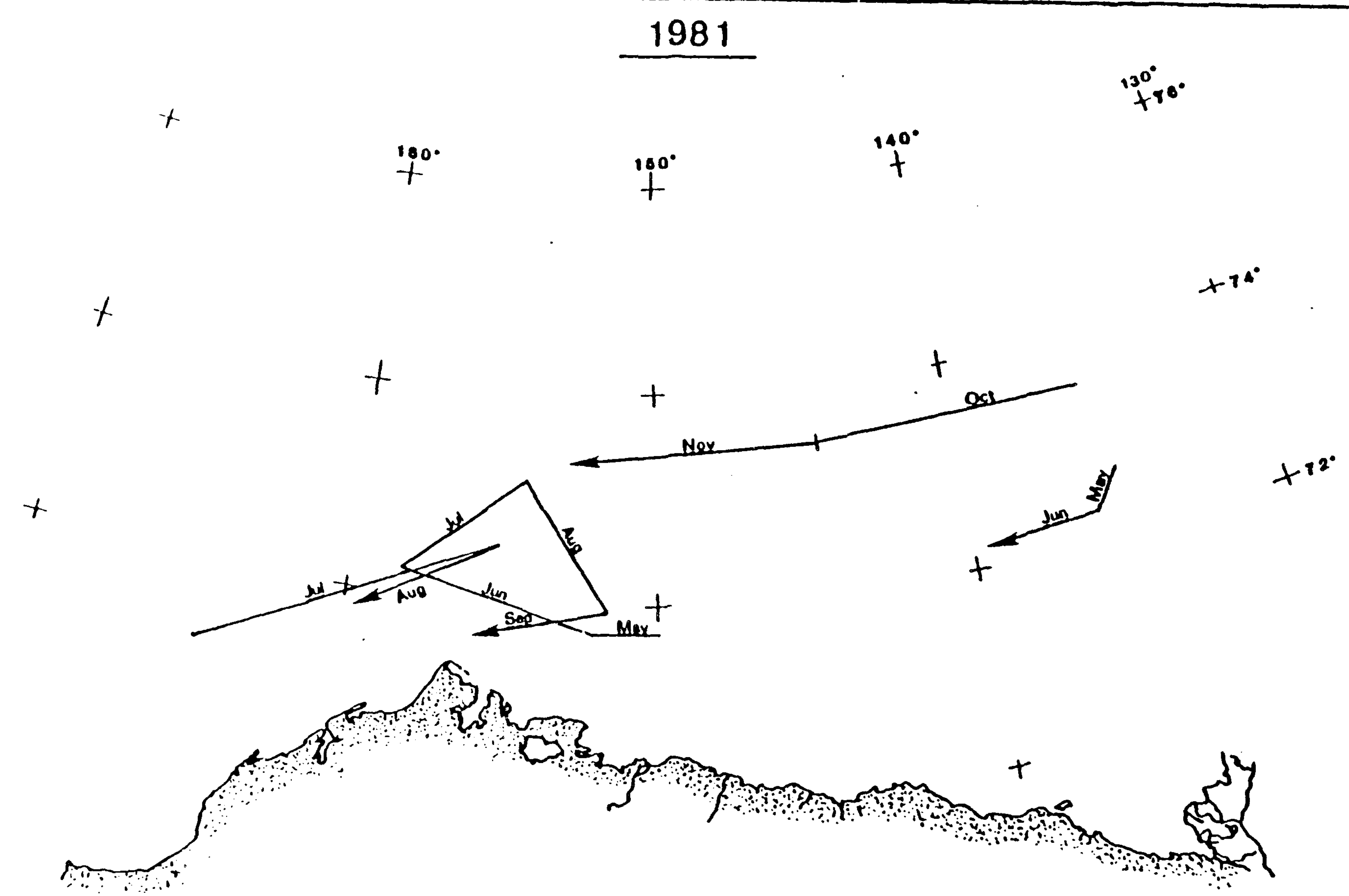


FIGURE 38 - TRACK OF ICE DRIFTER BUOYS OFF THE ALASKAN COAST IN 1981.

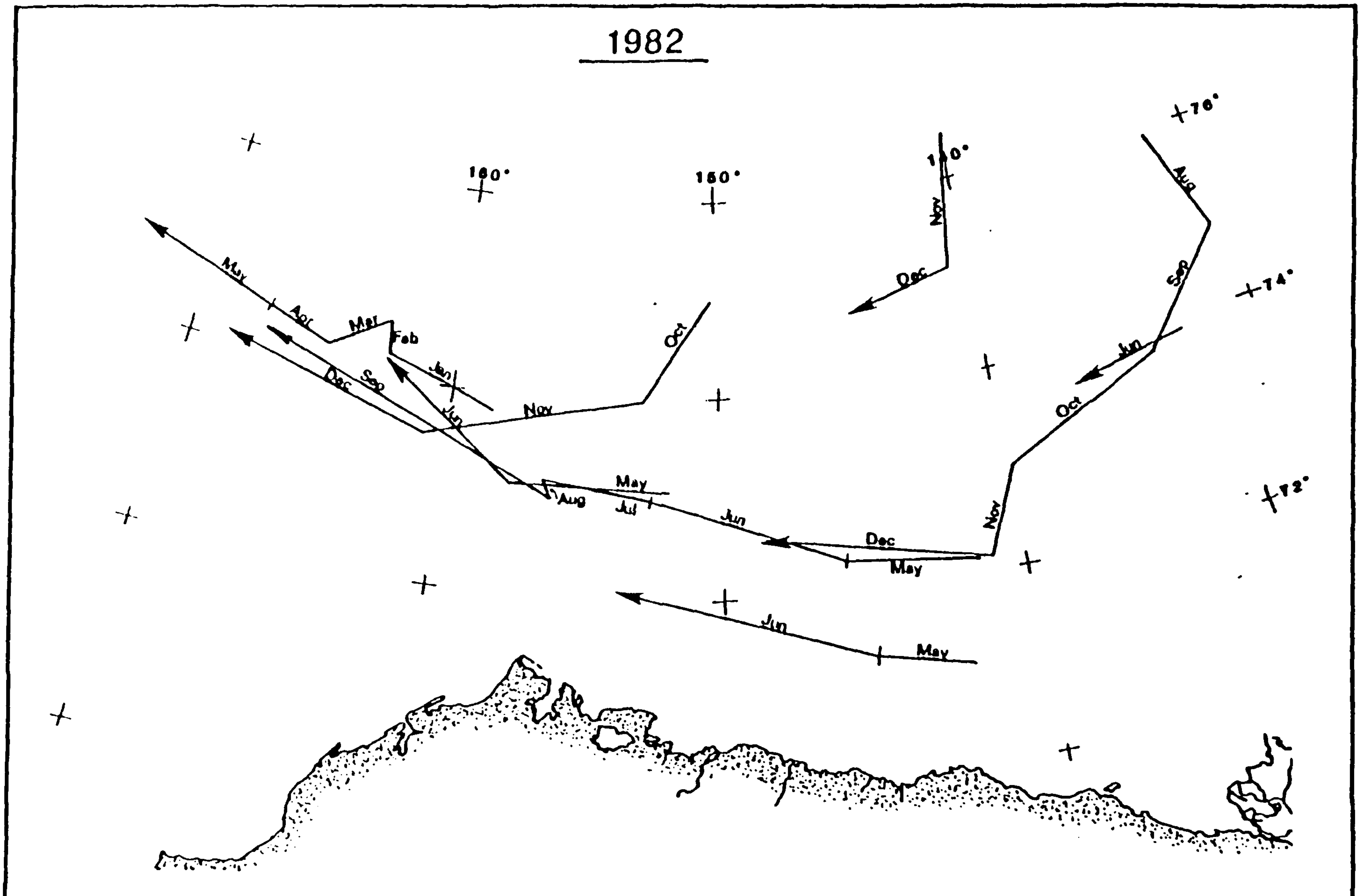


FIGURE 39 - TRACK OF ICE DRIFTER BUOYS OFF THE ALASKAN COAST IN 1982.

BATHYMETRY

10.0. BATHYMETRY

Figures 40 through 49 which follow display generalized bathymetry of the nearshore Beaufort Sea. These contours were derived from NOS Nautical Charts and U.S. Geological Survey 7-1/2' maps. In the nearshore Beaufort Sea, bathymetry changes rapidly and, at times, drastically. Coastal erosion rates are high (1.6 m/yr average over the whole coast), and result from both mechanical and thermal processes. (Hopkins and Hartz, 1978). As a result of this erosional pattern, sediment moved longshore during the open water season can rapidly change water depths and location of navigable channels. This makes navigational charts and bathymetric maps unreliable for all but small boats.

The maps which follow are intended to give the reader a general overview of the expected depth contours in the coastal zone.

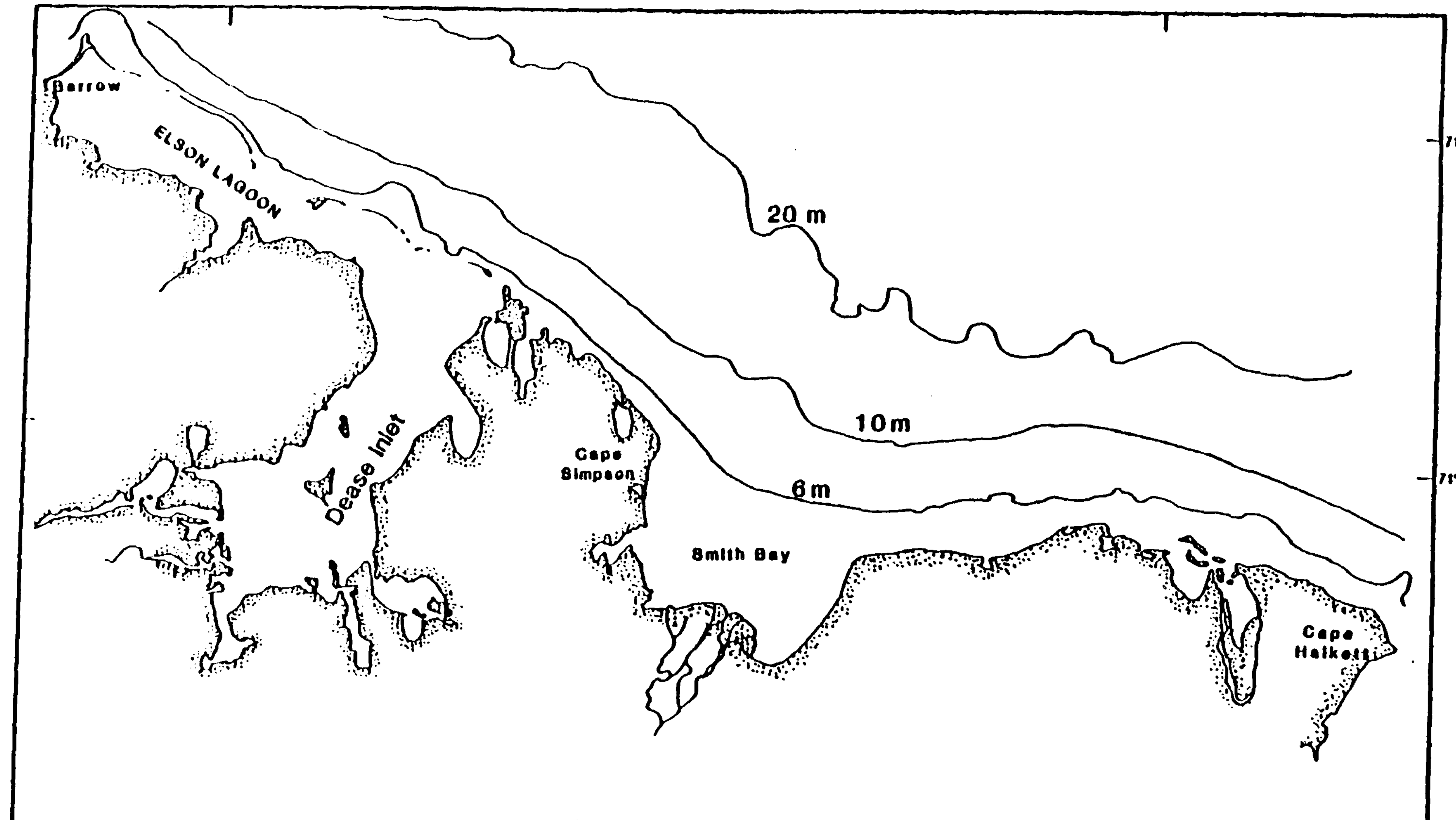


FIGURE 40 - DEPTH CONTOURS FROM BARROW TO CAPE HALKETT.

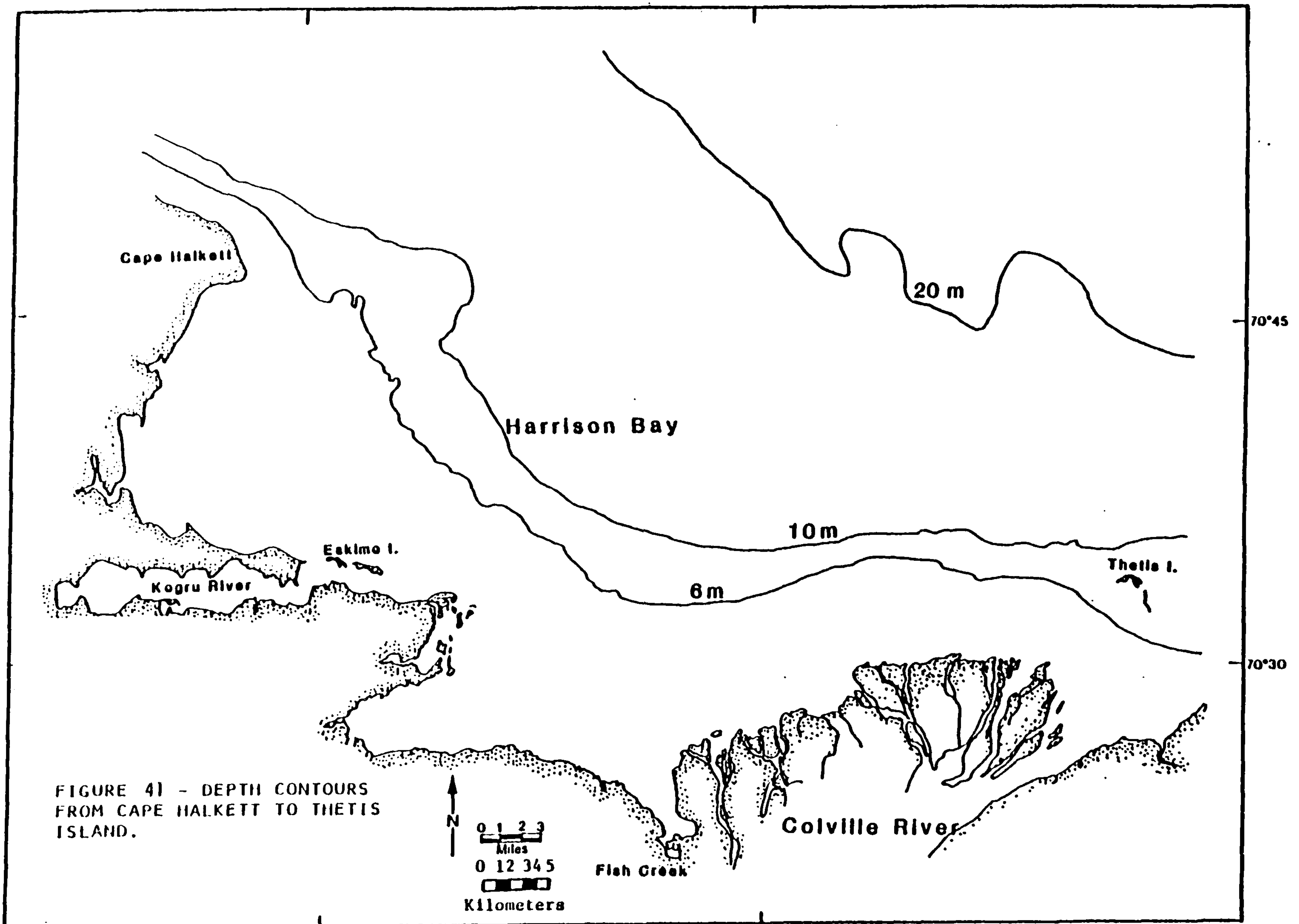


FIGURE 41 - DEPTH CONTOURS FROM CAPE HALKETT TO THETIS ISLAND.

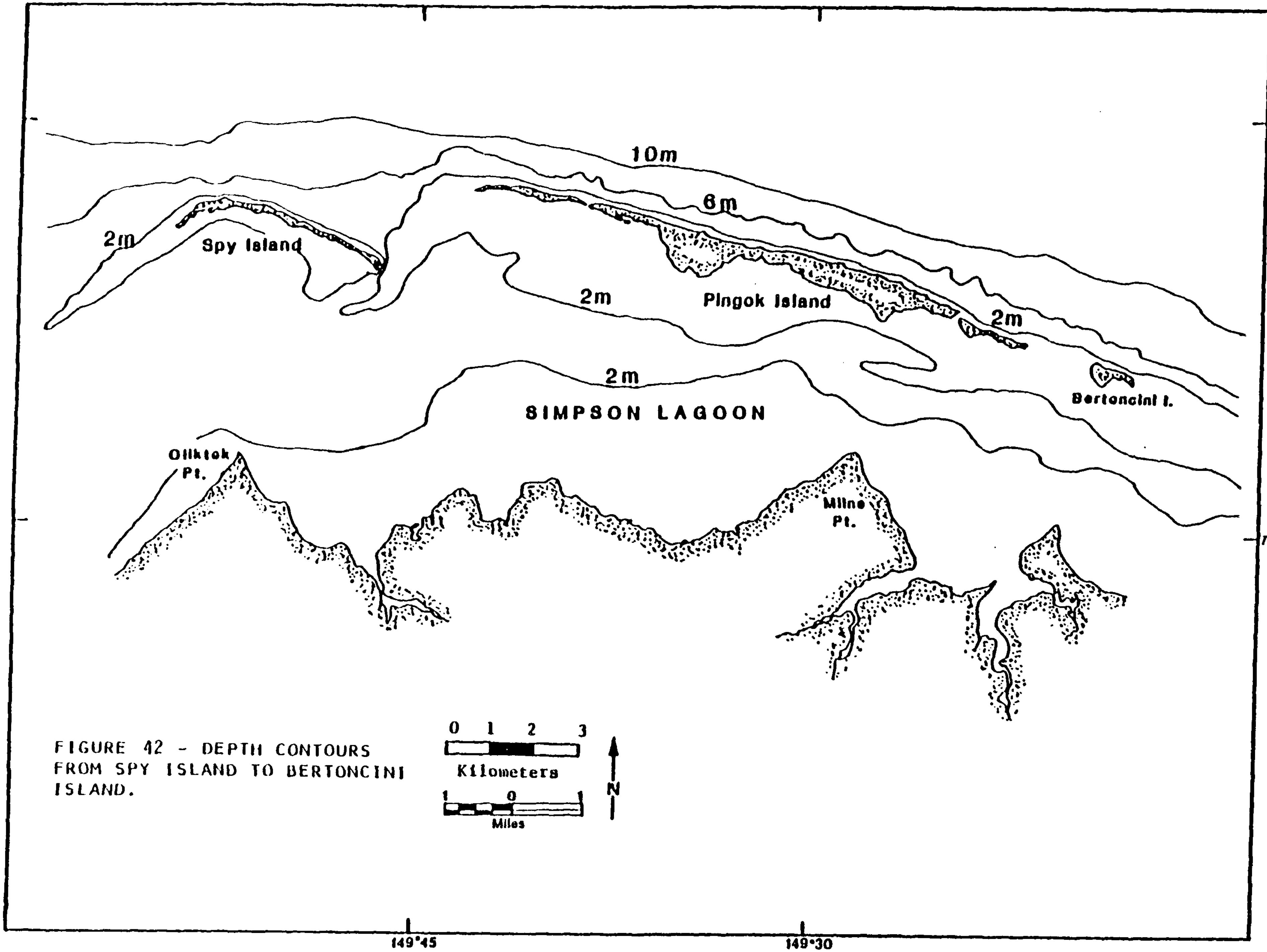


FIGURE 42 - DEPTH CONTOURS FROM SPY ISLAND TO BERTONCINI ISLAND.

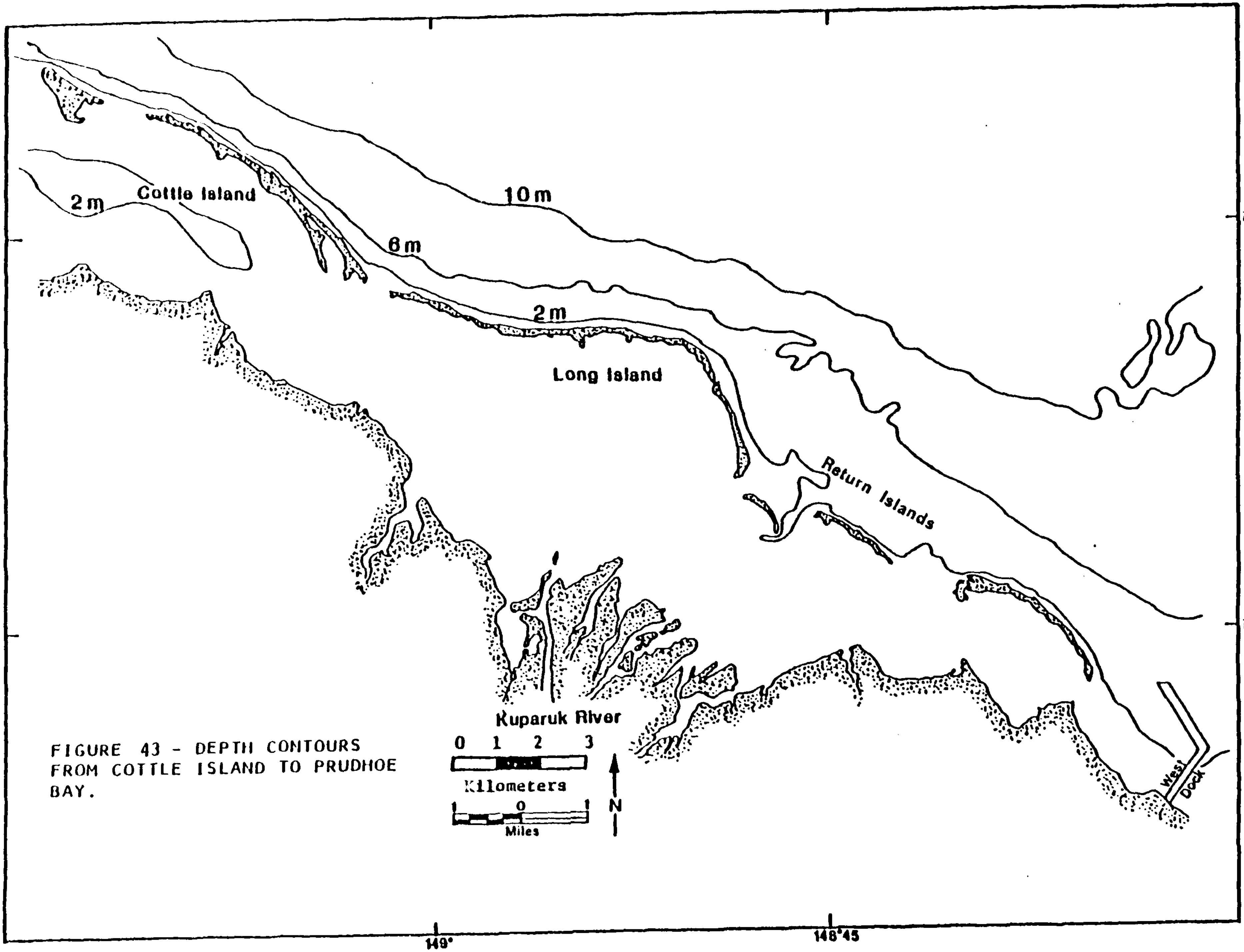


FIGURE 43 - DEPTH CONTOURS FROM COTTLE ISLAND TO PRUDHOE BAY.

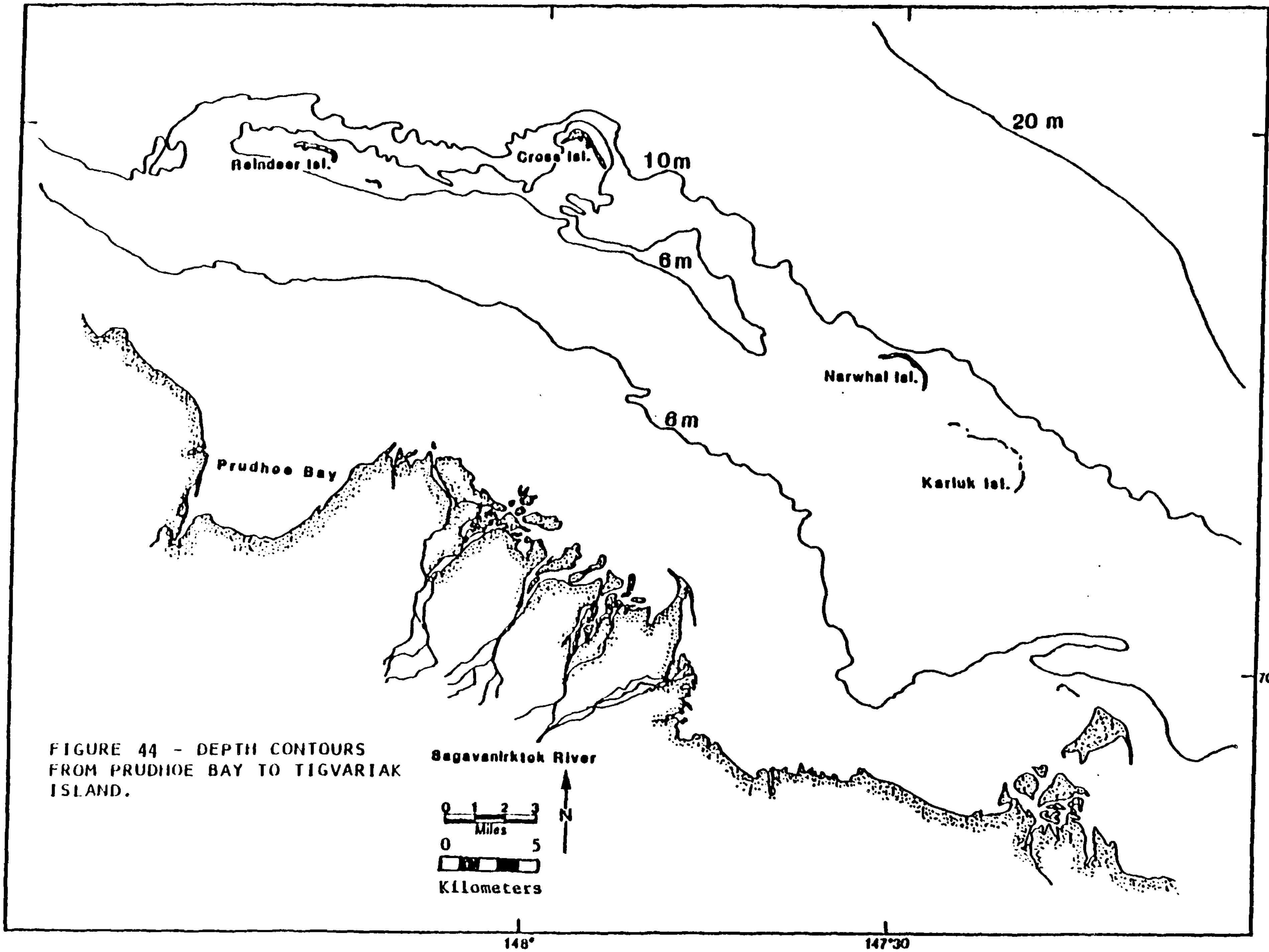


FIGURE 44 - DEPTH CONTOURS FROM PRUDHOE BAY TO TIGVARIAK ISLAND.

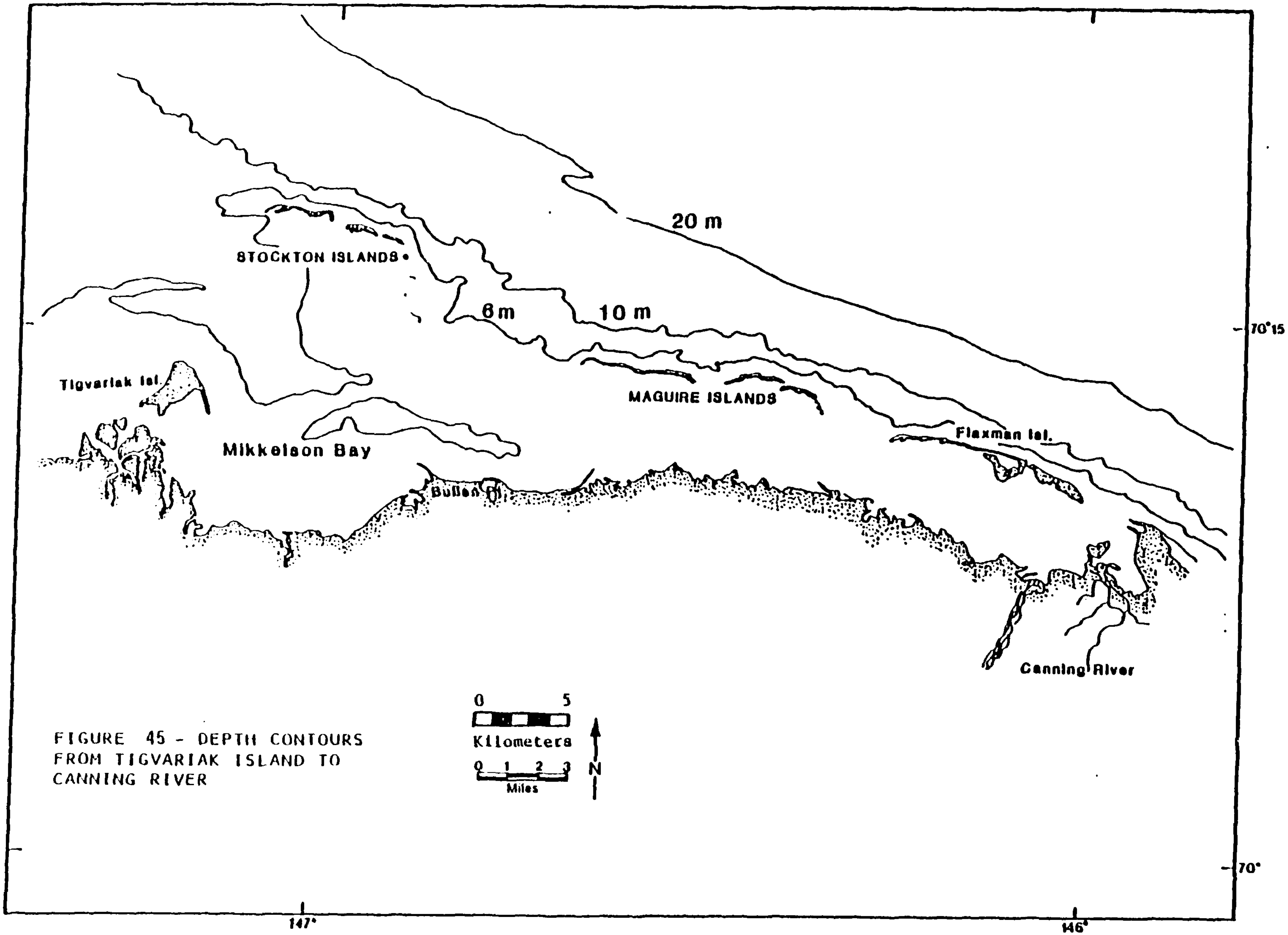


FIGURE 45 - DEPTH CONTOURS FROM TIGVARIAK ISLAND TO CANNING RIVER

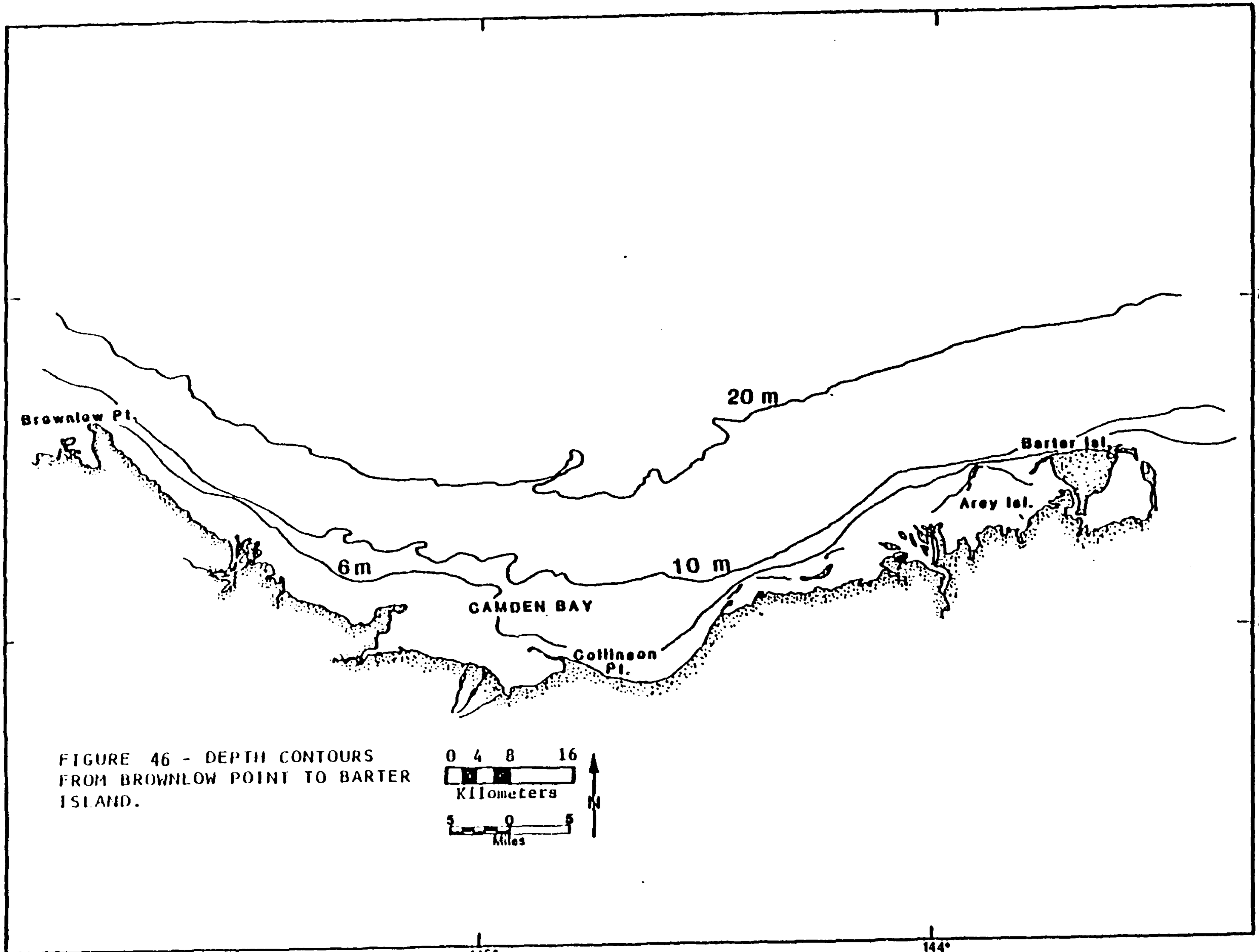


FIGURE 46 - DEPTH CONTOURS FROM BROWNLOW POINT TO BARTER ISLAND.

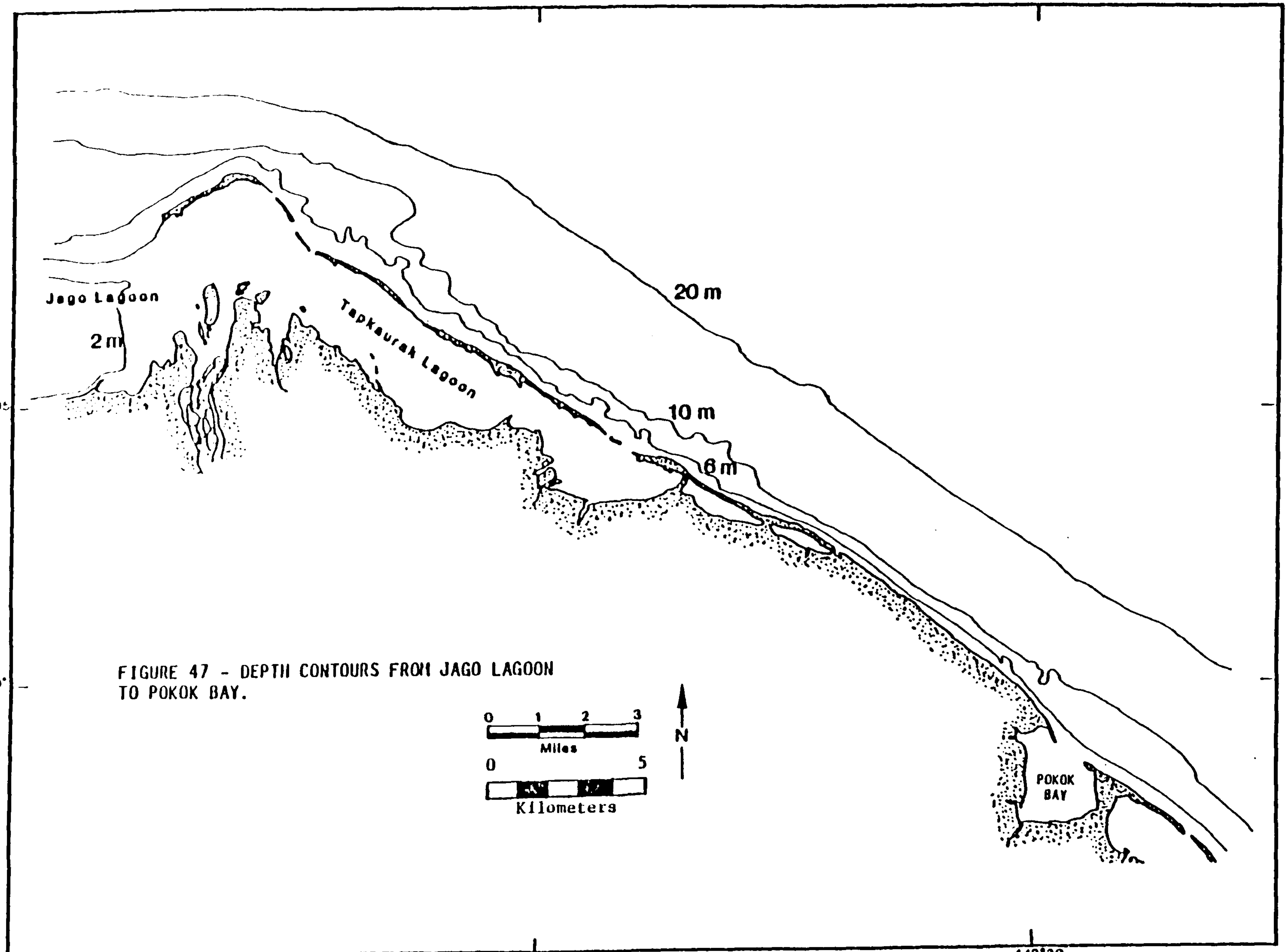


FIGURE 47 - DEPTH CONTOURS FROM JAGO LAGOON TO POKOK BAY.

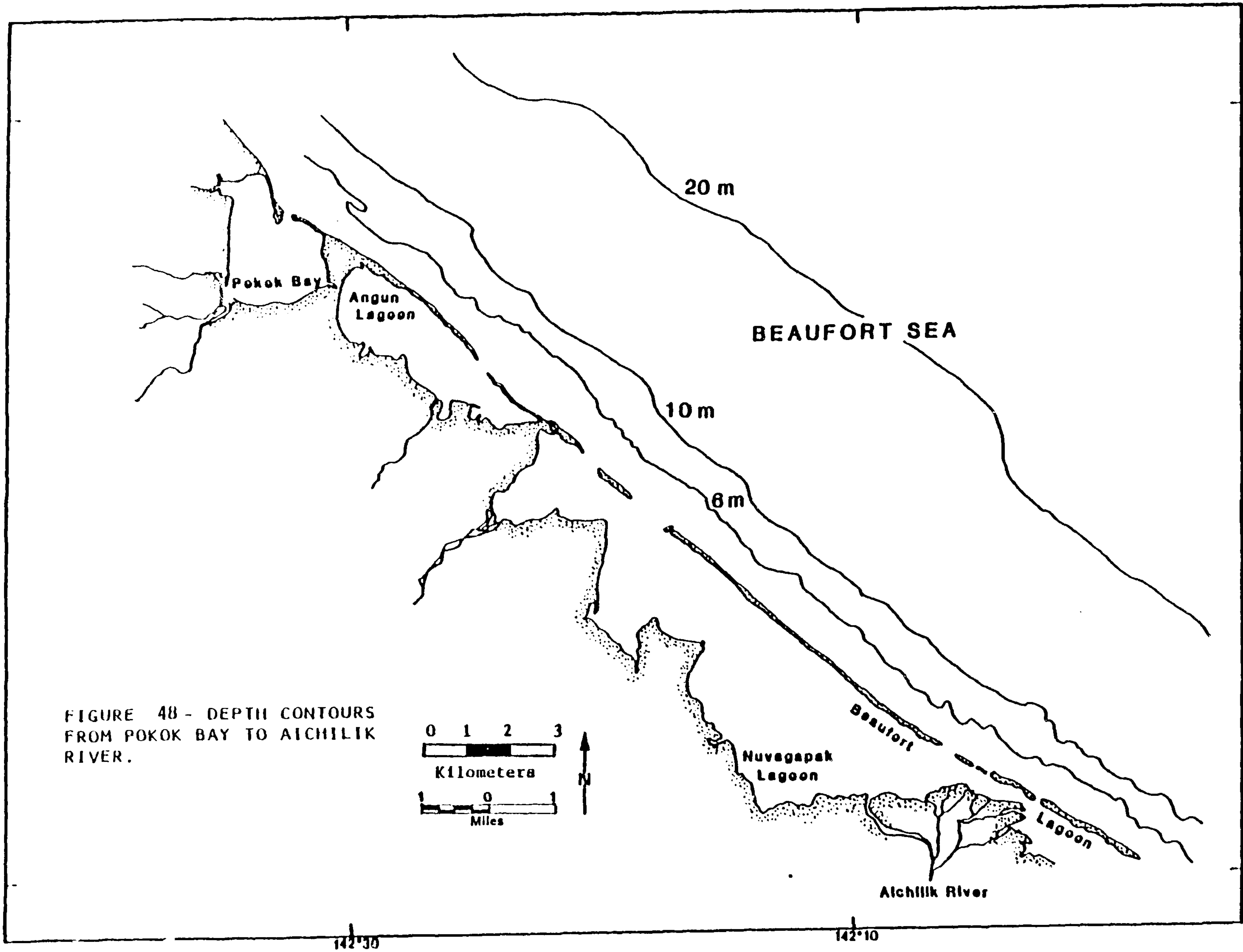


FIGURE 48 - DEPTH CONTOURS FROM POKOK BAY TO AICHILIK RIVER.

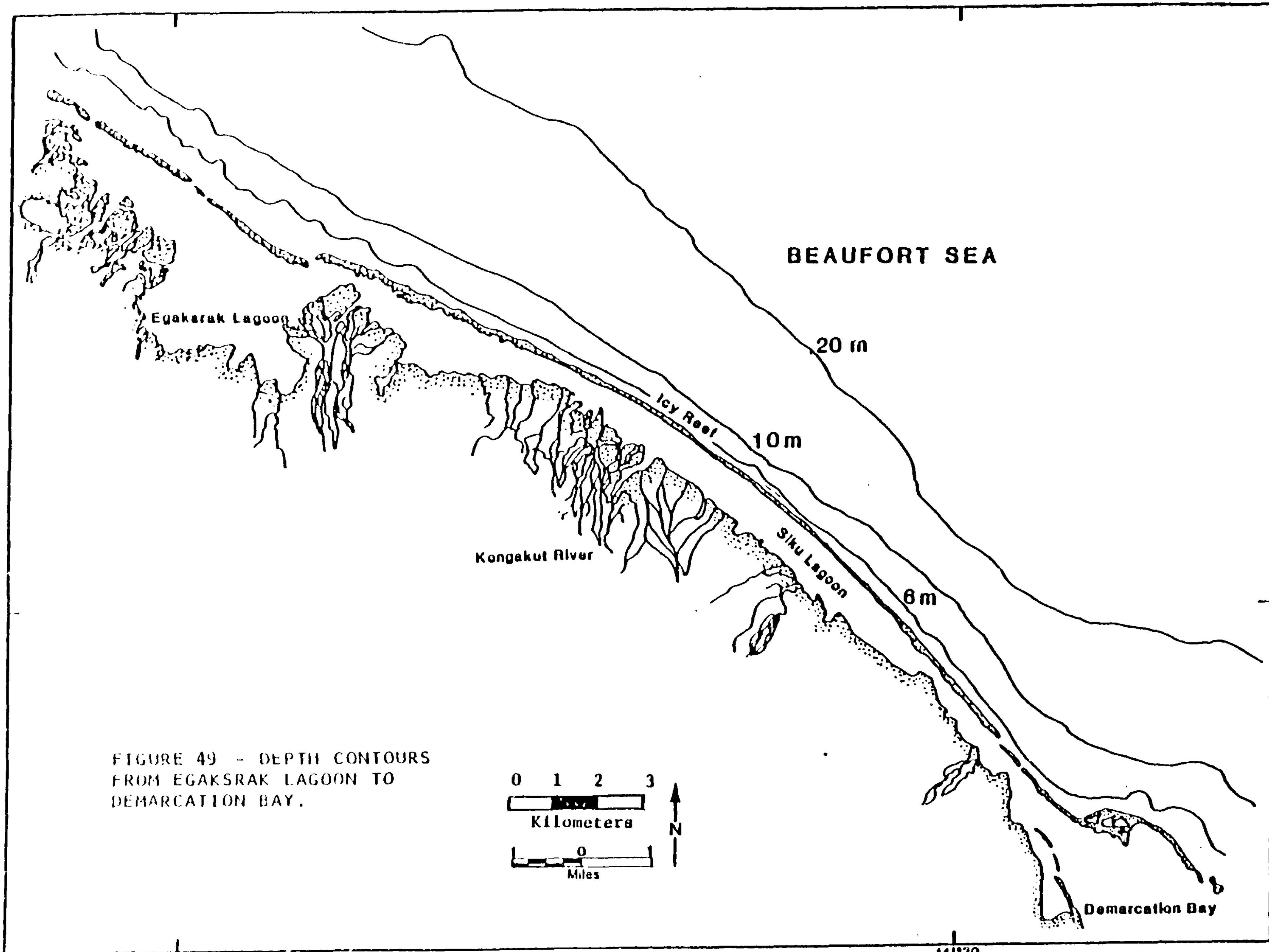


FIGURE 49 - DEPTH CONTOURS FROM EGAKSRAK LAGOON TO DEMARCATION BAY.

AD-A149 545 ATLAS OF THE BEAUFORT SEA(U) COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CT I M LISSAUER ET AL. OCT 84 CGR/DC-17/84 USCG-D-33-84 2/2

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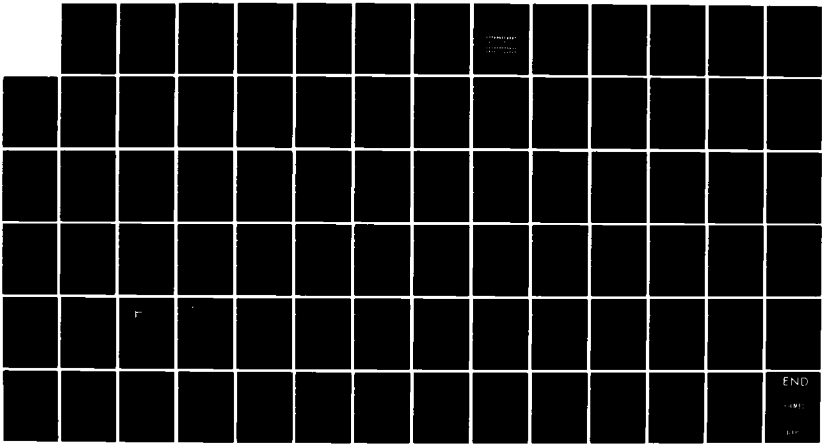
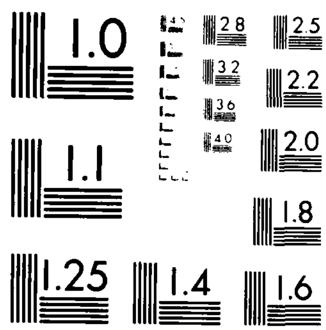




MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

SECTION B
METEOROLOGY

WINDS

11.0 WINDS

Figure 50 shows the coastal areas of Alaska. Figure 51 presents the major geographic areas along the Beaufort Sea coast. For this entire coastline, which runs several hundred miles, long-term wind data is available from only two sites, Point Barrow and Barter Island. This data collected every three hours is available from 1942 to the present. A source of wind data, over shorter term, is from Prudhoe Bay, Alaska. This data covers the last fifteen years. Other sporadic sources of data are available but because of their nature cannot be used to develop climatological data bases. Hufford et al. (1976) examined wind data from several sources and concluded that the most apparent and consistent feature of the surface winds along the north Alaskan coast is the persistence of easterly winds throughout the year (figure 52). The cause of these predominantly easterly winds is the atmospheric high pressure area centered over the Arctic in the eastern Beaufort Sea. The generalized effect of this atmospheric system can be seen in the prevailing wind directions for the Arctic Basin during both the mid-winter and mid-summer months (figures 53 and 54). For both these time periods the prevailing easterlies are apparent along the North Alaskan Coast. The predominant easterly winds are punctuated by westerly winds particularly during the late summer and early fall. These westerly winds are more apparent at Barter Island than at Point Barrow (figure 52). The westerly winds are attributed to low pressure systems moving eastward over the Arctic Ocean (figure 55). Searby and Hunter (1971) analyzed the winds at Barter Island and Point Barrow and provided mean monthly wind speeds for sixteen directions of the compass (tables 4 and 5), and the monthly percentage frequency occurrence of wind directions for sixteen directions of the compass (tables 6 and 7). The strongest winds occur from the east-northeast and west directions during the late summer through the fall when low pressure systems, discussed previously, reach a maximum in intensity and numbers. Table 8 provides percentage frequency of occurrence by speed groups of the wind for each month and for sixteen directions of the compass for Point Barrow and Barter Island. The predominant wind speed group on a monthly basis is 4 to 12 miles per hour ($\sim$2 to 6 m/s). The secondary wind speed group is 13 to 24 miles per hour ($\sim$ 6 to 10 m/s). These two speed groups account for approximately 90 percent of the measured winds at Barrow and 80 percent at Barter Island. Table 9 shows the frequency of occurrence of wind speed and direction for Barter Island. Table 10 provides further information on the average winds in the Beaufort Sea for Point Barrow, Prudhoe Bay and Barter Island. The mean wind speeds range between 4.2 and 6.8 meters per second ($\sim$9 to 15 mph). Thus the energy of the winds on the average is not high. However, more energetic winds can occur as indicated in table 11.

Recent research work by Kozo (1980 and 1982) has investigated mesoscale phenomena along the Beaufort Sea coast which affect the wind field which in turn is responsible for near shore surface water movement. The phenomena studied were mountain barrier baroclinicity and sea breeze forcing. Mountain barrier baroclinicity is a predominantly wintertime phenomenon caused by the Brooks Range. The basic cause of this phenomenon is a piling up of cold air against the Brooks Range. This causes a pressure gradient which is favorable to west winds. The ultimate result is a 180° surface wind shift along the Alaskan Arctic coast between Point Barrow and Barter Island during moderate wind conditions. Such shifts are not explained by the National Weather Service synoptic charts. Kozo (1980) indicates that this phenomenon is a major physical process responsible for the wintertime abundance of westerly

winds from Prudhoe Bay to the east. Likewise the frequency of westerly winds during wintertime is less from Prudhoe Bay west to Point Barrow.

The second mesoscale phenomenon investigated by Kozo (1982) was sea breeze forcing. This phenomenon results in a pressure gradient that accelerates the movement of air from sea to land. Kozo's data indicates that the sea breeze can dominate the surface wind direction at least 25% of the time during the summer in a zone at least 20 km landward and 20 km seaward of the coast.

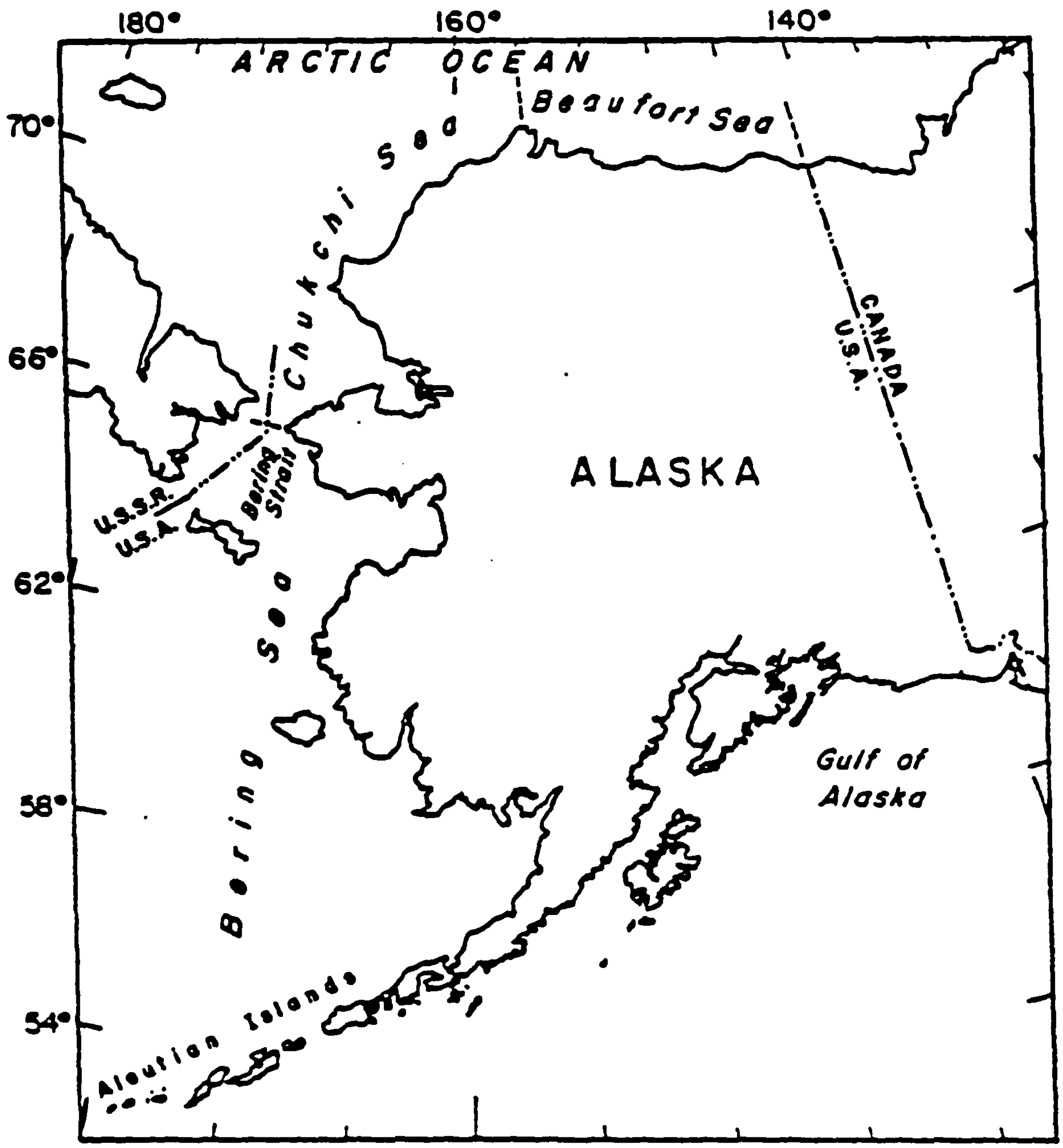


FIGURE 50 - GENERAL LOCATION MAP OF COASTAL AREAS OF ALASKA

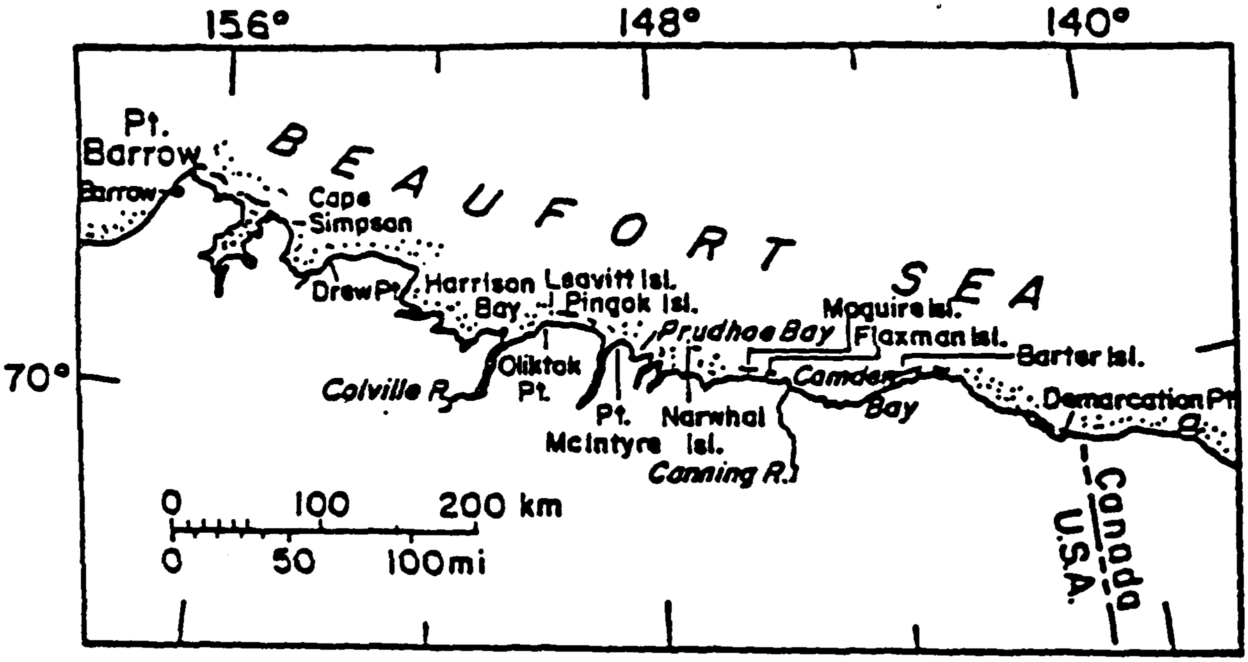


FIGURE 51 - GEOGRAPHIC LOCATIONS ALONG THE BEAUFORT SEA COAST FROM THE U.S.-CANADIAN BORDER

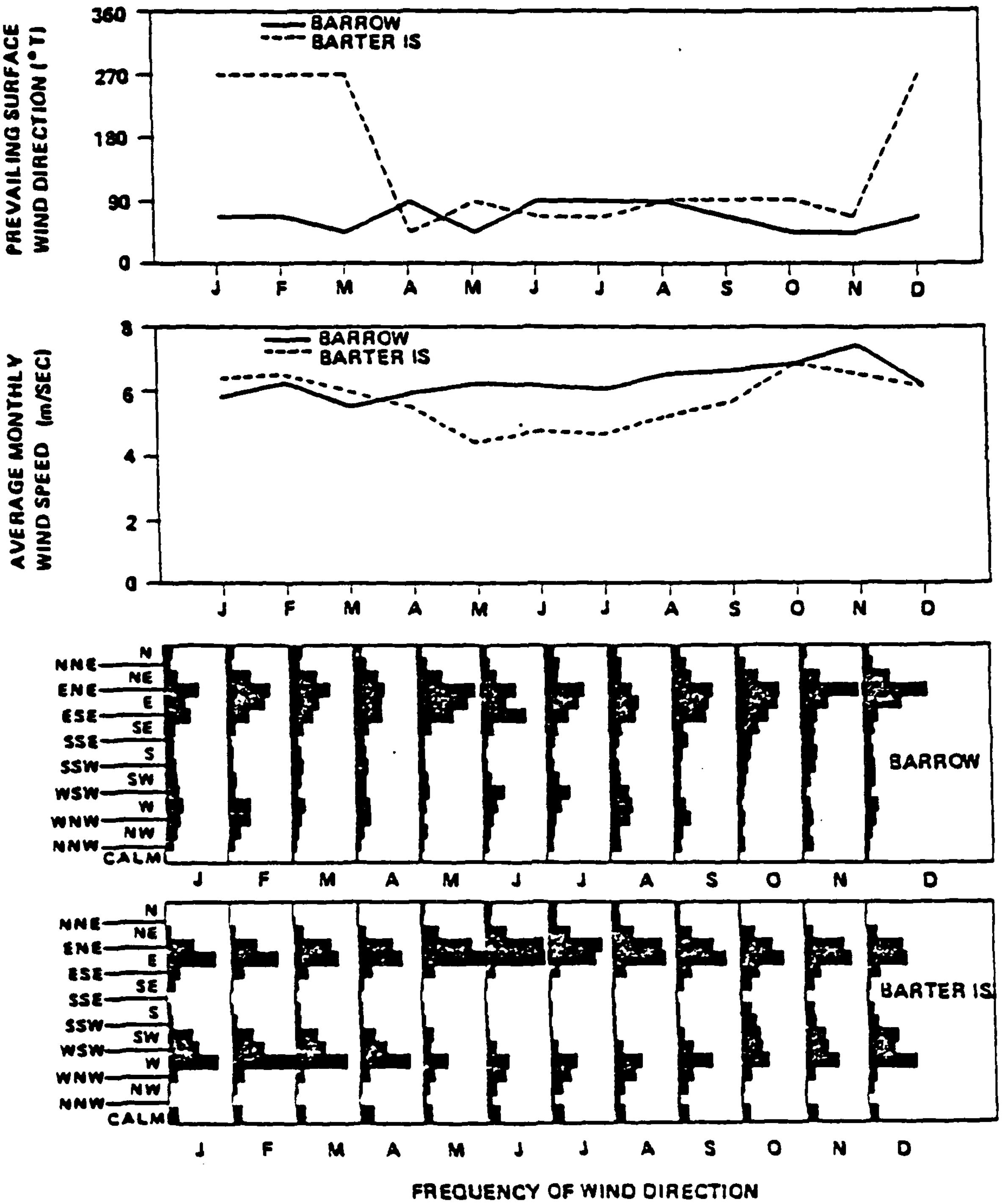


FIGURE 52 - CHARACTERISTICS OF THE WIND AT POINT BARROW AND BARTER ISLAND (BASED ON 42 YEARS OF DATA)

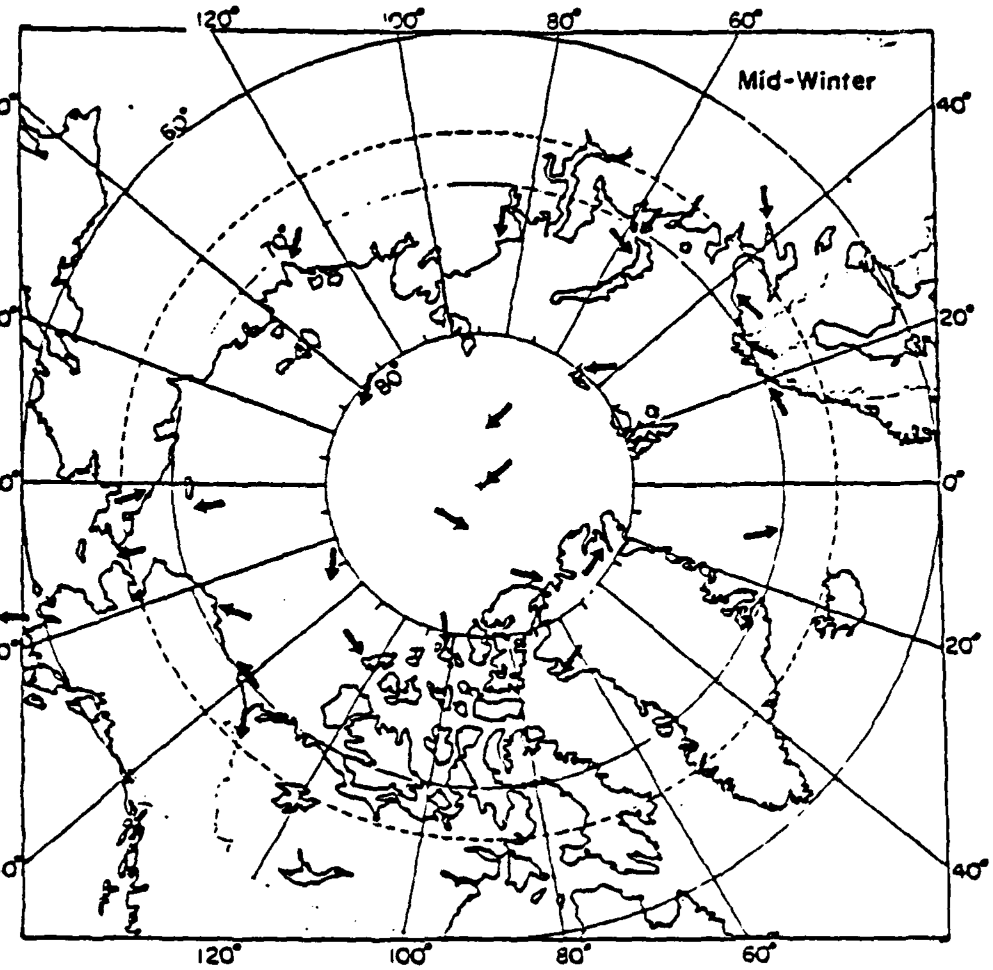


FIGURE 53 - PREVAILING WIND DIRECTIONS IN THE ARCTIC BASIN DURING THE MID-WINTER MONTHS (FROM BILLELO, 1973)

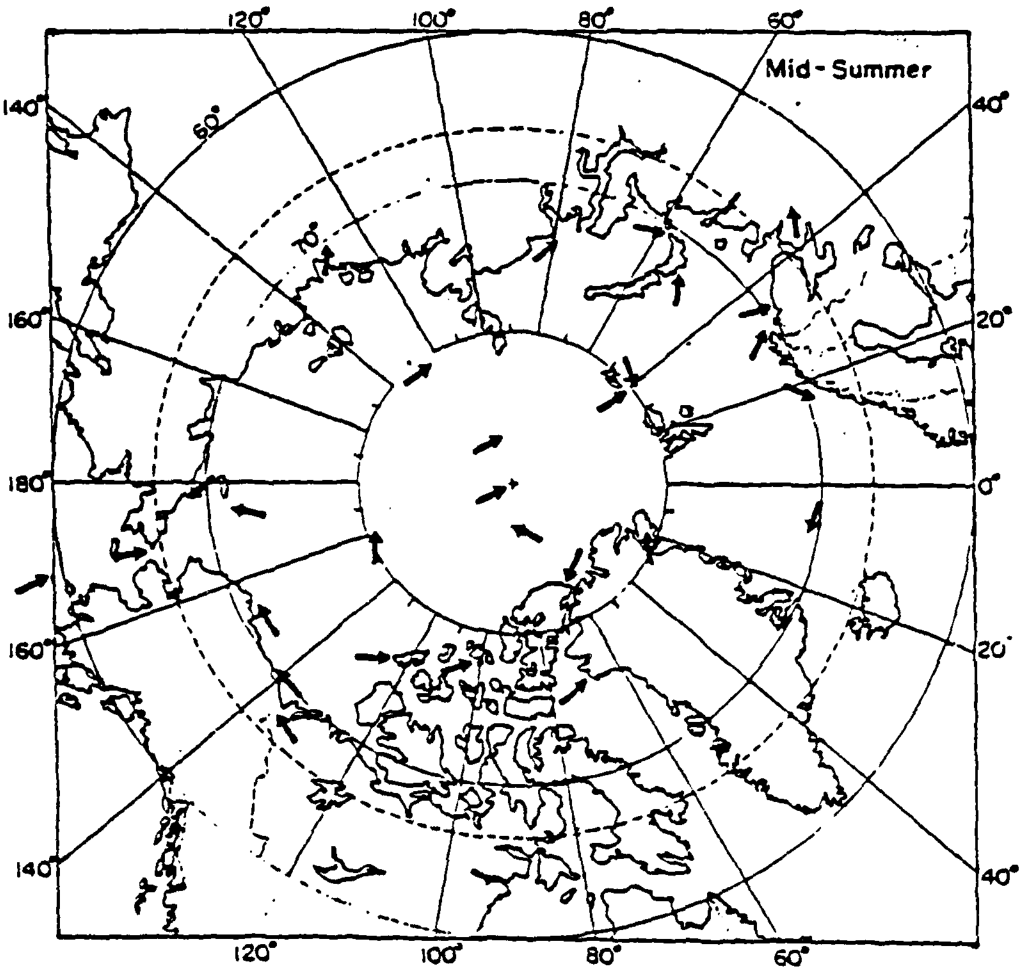


FIGURE 54 - PREVAILING WIND DIRECTIONS IN THE ARCTIC BASIN DURING THE MID-SUMMER MONTHS (FROM BILLELO, 1973)

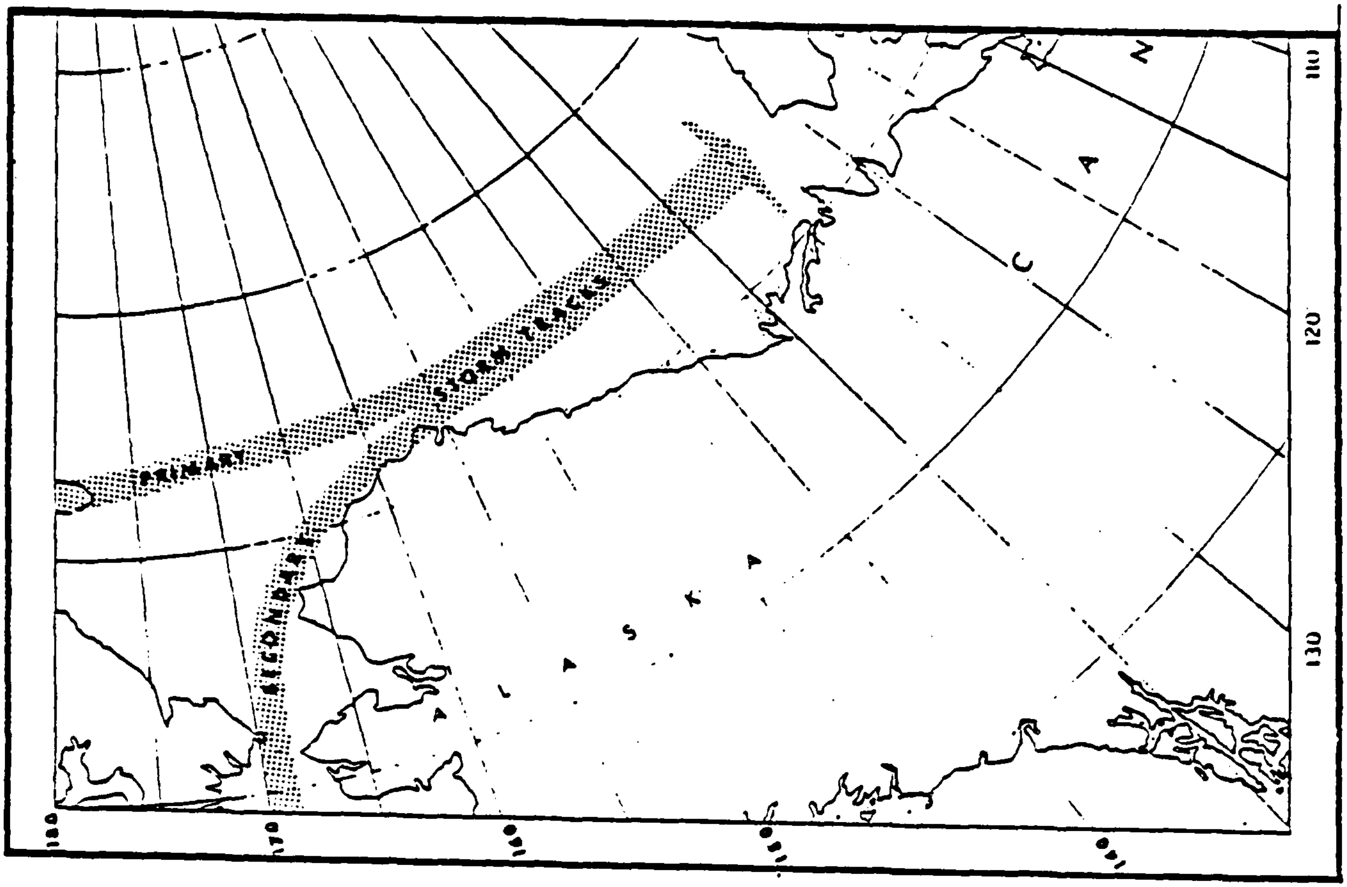


FIGURE 55 - PRIMARY AND SECONDARY STORM TRACKS FOR THE NORTH SLOPE OF ALASKA

Table 4

MEAN MONTHLY WIND SPEED VALUES FOR SIXTEEN DIRECTIONS OF THE COMPASS
BARTER ISLAND

BARTER ISLAND WIND SPEED - MEAN VALUES

(IN METERS PER SECOND)

	J	F	M	A	M	J	J	A	S	O	N	D
N	2.7	2.9	2.2	2.4	2.4	2.3	2.5	2.6	3.2	3.8	2.6	2.5
NNE	3.0	2.5	2.9	2.9	2.6	2.7	2.7	2.9	3.2	4.2	3.2	2.9
NE	3.8	3.9	3.9	4.2	4.1	3.4	4.0	4.2	4.9	7.4	5 [illegible]	4.2
ENE	6.4	6.0	7.1	6.3	5.8	5.7	5.4	6.4	6.6	9.0	[illegible]	6.6
E	6.9	6.6	6.8	6.5	7.0	6.2	5.7	7.0	7.1	10.[illegible]	8.7	7.7
ESE	4.5	5.1	5.0	4.9	5.2	5.2	4.7	4.8	5.5	5.9	[illegible]	5.0
SE	4.2	3.0	3.3	3.7	3.2	3.7	3.2	3.5	4.4	4.2	3.6	3.3
SSE	5.0	2.9	3.0	3.5	2.6	2.9	3.3	3.0	3.1	3.0	2.8	3.1
S	3.6	3.2	3.1	3.4	3.3	2.6	3.2	3.1	3.2	3.5	3.3	3.4
SSW	3.2	3.2	2.9	3.0	2.8	2.7	3.3	3.3	3.3	3.6	3.6	3.5
SW	3.9	3.9	3.8	3.7	3.8	3.3	3.8	4.3	4.1	4.2	4.1	4.4
WSW	8.0	6.2	5.2	4.9	4.4	5.1	5.6	5.9	6.3	6.9	6.0	6.1
W	9.7	10.0	8.5	7.9	6.3	5.4	5.7	5.7	7.2	8.7	8.1	8.6
WNW	7.7	9.1	7.1	6.9	5.5	4.6	5.0	4.9	5.4	7.1	6.9	7.3
NW	4.0	4.3	3.1	3.5	3.0	3.1	3.2	3.3	3.9	5.2	4.8	4.8
NNW	3.7	2.5	2.8	2.6	2.9	2.6	2.7	2.8	3.2	4.1	2.8	3.0
MONTHLY AVERAGE SPEED												
	6.4	6.5	6.0	5.5	4.4	4.7	4.6	5.2	5.6	6.8	6.5	6.1

Table 5

MEAN MONTHLY WIND SPEED VALUES FOR SIXTEEN DIRECTIONS OF THE COMPASS
POINT BARROW

BARROW WIND SPEED - MEAN VALUES

(IN METERS PER SECOND)

	J	F	M	A	M	J	J	A	S	O	N	D
N	4.4	3.8	4.6	4.6	3.7	3.8	3.7	4.1	5.6	6.1	6.1	4.2
NNE	4.3	4.1	5.8	5.4	5.3	4.4	4.4	5.3	6.0	6.8	6.1	4.8
NE	5.1	4.9	5.3	5.2	5.6	5.4	5.6	5.3	5.9	6.7	7.3	5.8
ENE	6.4	7.2	6.4	6.4	6.8	6.8	7.4	7.9	7.4	8.0	9.0	7.3
E	6.4	7.5	6.0	6.6	7.4	7.6	6.8	7.9	7.5	8.1	7.5	6.2
ESE	8.1	6.7	6.4	7.2	7.0	7.3	6.9	7.0	7.2	6.3	6.2	5.4
SE	5.5	4.2	5.3	5.4	6.1	5.4	6.0	5.4	5.2	5.2	4.9	4.0
SSE	4.5	4.0	4.6	4.9	3.9	4.7	5.9	5.3	5.6	5.0	5.6	3.5
S	4.2	4.5	4.4	5.2	4.1	4.6	5.7	5.2	4.9	5.9	6.0	4.2
SSW	5.3	6.2	5.2	6.4	4.9	4.6	6.3	6.8	6.1	6.1	7.5	5.9
SW	4.8	6.1	4.8	5.4	5.7	5.4	6.2	5.9	6.3	5.9	7.8	5.4
WSW	6.4	8.1	6.5	6.5	6.1	6.4	6.5	7.7	6.6	8.2	9.7	6.3
W	6.9	6.7	5.6	6.1	5.4	5.2	5.7	6.5	7.5	7.4	8.7	7.7
WNW	5.6	6.4	5.4	6.5	5.6	4.9	4.6	6.3	7.8	6.9	7.3	7.5
NW	4.8	5.5	3.9	5.2	3.8	4.5	4.4	5.8	6.4	5.9	6.9	6.1
NNW	4.9	4.6	4.3	4.2	4.4	4.3	4.1	5.4	6.0	6.4	6.5	4.2
MONTHLY AVERAGE SPEED	5.8	6.2	5.5	5.9	6.2	6.1	6.0	6.5	6.6	6.8	7.4	6.1

Table 6

MONTHLY PERCENTAGE FREQUENCY OF OCCURRENCE OF WIND DIRECTION FOR SIXTEEN DIRECTIONS OF THE COMPASS - BARTER ISLAND

BARTER ISLAND

WIND DIRECTION
(PERCENTAGE FREQUENCY OF OCCURRENCE)

	J	F	M	A	M	J	J	A	S	O	N	D
N	.4	.4	.5	.8	1.8	2.6	2.8	2.5	1.9	.9	.6	.9
NNE	.5	.3	.7	.9	1.5	2.3	3.1	3.0	2.2	1.2	1.0	.5
NE	2.6	2.3	4.3	2.9	7.2	8.7	9.4	8.1	6.6	6.8	4.3	3.9
ENE	10.8	10.6	15.2	13.9	20.1	23.6	21.2	19.8	15.0	13.0	16.2	14.5
E	19.8	18.5	17.5	17.6	29.4	24.3	18.2	20.7	20.0	17.3	18.9	15.7
ESE	5.3	5.3	5.1	5.7	5.1	3.0	4.5	5.7	6.9	7.2	6.7	5.0
SE	3.9	1.1	1.7	2.1	1.1	.9	1.5	1.8	3.0	4.1	3.6	1.6
SSE	.9	.6	.4	.8	.5	.5	.7	.9	1.0	1.2	1.0	.7
S	1.9	1.7	1.5	1.9	.9	.7	1.5	1.4	1.8	4.3	3.3	2.1
SSW	2.2	2.4	2.2	2.0	1.2	.6	.7	1.2	1.7	6.1	4.5	4.2
SW	10.3	8.9	9.2	7.0	4.6	1.3	1.4	1.8	3.1	7.4	8.0	12.0
WSW	12.4	13.3	12.2	11.6	3.9	3.7	3.6	3.7	6.4	8.1	9.4	10.7
W	19.1	24.9	21.3	20.5	10.2	9.3	11.0	11.2	13.6	11.8	13.4	19.5
WNW	4.0	4.8	3.8	4.4	5.2	7.7	7.9	8.9	6.4	4.2	3.0	2.9
NW	1.1	.9	.9	1.4	2.6	4.3	5.0	4.5	4.0	1.9	1.1	1.7
NNW	.2	.1	.3	.4	1.3	1.8	2.0	2.2	1.7	.8	.4	.3
CALM	4.7	4.0	4.1	6.1	3.4	4.8	5.5	3.7	4.6	3.7	4.6	3.8

PREVAILING DIRECTION UNDERLINED

TABLE 7

MONTHLY PERCENTAGE FREQUENCY OF OCCURRENCE OF WIND DIRECTION FOR SIXTEEN DIRECTIONS OF THE COMPASS - POINT BARROW

BARROW

WIND DIRECTION
(PERCENTAGE FREQUENCY OF OCCURRENCE)

	J	F	M	A	M	J	J	A	S	O	N	D
N	3.9	3.4	5.0	3.7	2.1	2.5	4.3	4.3	3.7	2.0	3.1	2.6
NNE	3.8	2.5	4.8	5.3	3.9	3.6	6.1	5.5	5.9	3.7	2.0	3.9
NE	6.2	10.1	11.9	9.4	9.9	6.5	5.8	5.4	7.4	8.3	7.8	11.2
ENE	14.3	17.4	16.0	12.3	22.7	13.4	15.7	9.4	16.2	17.2	23.4	27.7
E	8.2	15.0	12.9	11.4	19.7	10.2	12.9	12.0	14.3	16.8	11.7	15.2
ESE	11.4	7.9	9.1	11.3	13.6	17.4	9.3	11.4	13.9	12.0	7.1	6.3
SE	5.4	3.7	5.4	6.0	5.5	5.2	5.3	4.8	4.7	8.6	5.9	4.3
SSE	3.1	1.9	2.4	3.7	2.1	2.2	3.6	4.1	5.3	6.5	5.6	2.2
S	3.1	2.3	4.1	4.6	2.1	1.7	2.5	2.8	3.1	5.5	6.4	2.8
SSW	5.2	2.3	4.7	5.0	2.3	2.0	3.2	3.8	2.8	4.3	6.0	3.0
SW	5.4	3.1	3.9	4.4	2.9	3.1	5.2	4.1	2.8	3.0	3.4	3.1
WSW	5.9	2.9	3.3	4.5	3.4	8.5	9.5	7.7	2.7	2.6	3.1	2.7
W	7.6	9.5	5.7	5.7	2.4	6.4	6.5	8.9	4.6	2.2	3.7	4.9
WNW	6.8	9.3	3.9	5.7	1.9	4.5	3.7	7.7	5.8	2.6	4.6	4.6
NW	4.8	5.3	3.3	3.6	2.6	3.6	2.9	3.4	3.1	1.7	3.2	2.4
NNW	3.8	2.4	2.4	2.4	1.6	2.2	2.5	4.1	2.7	2.3	4.5	1.6
Calm	1.2	0.8	1.2	1.0	1.1	0.9	1.1	0.7	1.0	0.6	0.4	1.5

PREVAILING DIRECTION UNDERLINED

TABLE 8

WIND-PERCENTAGE FREQUENCY OF OCCURRENCE BY SPEED GROUPS
FOR POINT BARROW AND BARTER ISLAND BY MONTH

EXTREME MONTHLY WIND SPEEDS FOR BOTH LOCATIONS BY MONTH
(1 mph = 0.4470416 m/s)

	WIND - PERCENTAGE FREQUENCY OF OCCURRENCE BY SPEED GROUPS														EXTREME WINDS (MPH)		
	BARROW							BARTER ISLAND									
	Calm	1 to 3 MPH	4 to 12 MPH	13 to 24 MPH	25 to 31 MPH	32 to 46 MPH	47 MPH and over	Calm	1 to 3 MPH	4 to 12 MPH	13 to 24 MPH	25 to 31 MPH	32 to 46 MPH	47 MPH and over	BARROW	UMIAT	BARTER ISLAND
Jan	1.3	6.1	59.6	27.5	4.0	1.4	0.1	4.7	6.4	44.0	29.2	7.4	6.8	1.4	56		75
Feb	0.8	7.5	53.4	31.2	4.7	2.3	0.1	4.0	5.3	43.2	32.8	6.9	6.2	1.7	58		65
Mar	1.2	5.8	60.3	30.9	1.7	0.1	0	4.1	6.7	44.9	32.8	6.5	4.2	0.8	58	DATA NOT AVAILABLE	77
Apr	1.0	4.6	57.2	33.1	3.8	0.3	0	6.1	6.4	47.0	31.2	5.6	3.5	0.2	52		52
May	1.1	3.1	52.3	41.9	1.5	0.1	0	3.4	6.4	48.3	36.7	3.6	1.6	0	43		55
Jun	0.9	2.5	54.9	40.4	1.3	0	0	4.8	6.2	53.9	33.1	1.6	0.3	0	38		38
Jul	1.0	3.6	52.5	42.0	0.9	0	0	5.5	5.8	56.6	30.6	1.3	0.2	0	56		40
Aug	0.6	2.7	53.6	37.7	4.2	1.2	0	3.7	5.5	52.8	32.8	3.7	1.5	0.1	47		46
Sep	1.0	3.1	46.1	46.4	3.1	0.3	0	4.6	5.9	47.4	34.3	5.1	2.2	0.4	56		78
Oct	0.8	2.7	49.2	40.6	5.5	1.2	0	3.7	4.5	40.2	33.9	9.8	7.5	0.4	55		58
Nov	0.3	3.8	43.4	42.2	6.9	3.2	0.2	4.6	5.9	42.0	31.0	9.0	6.6	0.8	63		67
Dec	1.4	6.9	50.4	38.0	2.8	0.5	0	3.0	6.8	45.9	31.6	6.9	4.0	1.0	70		75
Yr.	0.9	4.4	52.7	37.7	3.4	0.9	*	4.4	6.0	47.2	32.5	5.6	3.7	0.6	70		73

Table 9

PERCENTAGE FREQUENCY OF OCCURRENCE OF WIND DIRECTION AND SPEED FOR BARTER ISLAND
(FROM ISAKSON, ET AL., 1975)
(1 mph = 0.4470416 m/s)

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (MPH) (FROM HOURLY OBSERVATIONS)

BARTER ISLAND

SURFACE WINDS

	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	≥56	%	Mean Wind Speed
N	.4	.7	.3	.0	.0	.0						1.4	5.1
NNE	.3	.7	.4	.1	.0							1.4	5.7
NE	.5	1.6	1.9	.8	.2	.1	.0	.0	.0			5.2	8.6
ENE	.4	1.9	4.6	5.0	2.0	.9	.3	.1	.0	.0		15.2	12.3
E	.7	2.5	5.1	6.6	3.2	1.9	.8	.3	.1	.0		21.2	13.7
ESE	.4	1.3	1.9	1.2	.4	.2	.1	.0	.0			5.5	10.3
SE	.3	.7	.7	.2	.0	.0	.0	.0	.0			2.0	7.2
SSE	.2	.3	.3	.0	.0	.0	.0					.8	6.2
S	.3	.8	.8	.1	.0							2.0	6.4
SSW	.3	.8	1.0	.1	.0	.0						2.3	6.5
SW	.5	1.7	2.7	.7	.1	.0	.0	.0	.0	.0	.0	5.8	7.7
WSW	.3	1.3	3.4	1.9	.5	.3	.2	.1	.1	.0	.0	8.1	11.6
W	.4	1.5	3.9	4.7	2.4	1.7	1.0	.5	.1	.1	.0	16.4	15.5
WNW	.3	.9	1.6	1.3	.6	.3	.1	.0	.0	.0	.0	5.2	11.7
NW	.4	1.0	.7	.3	.1	.0	.0	.0		.0	.0	2.4	7.1
NNW	.2	.6	.2	.0	.0	.0						1.0	5.6
VARBL													
CALM												4.1	
	6.0	18.3	29.4	23.0	9.6	5.5	2.5	1.2	.3	.2	.1	100.0	11.2

TOTAL NUMBER OF OBSERVATIONS 162511

TABLE 10

a) AVERAGE WINDS IN THE BEAUFORT SEA AREA BY MONTH FOR POINT BARROW, PRUDHOE BAY AND BARTER ISLAND

Month	Barrow Mean Speed (m/s)	Barrow Prevailing Direction	Prudhoe Bay Mean Speed (m/s)	Prudhoe Bay Prevailing Direction	Barter Island Mean Speed (m/s)	Barter Island Prevailing Direction
January	5.1	ESE	6.8	W	6.6	W
February	4.9	E	5.9	W	6.3	W
March	5.0	ENE	5.4	W	6.1	W
April	5.1	NE	5.3	E	5.3	W
May	5.2	ENE	5.2	E	5.6	E
June	5.1	E	4.9	E	5.1	ENE
July	5.2	E	4.7	E	4.7	ENE
August	5.5	E	4.2	E	5.2	E
September	5.8	E	5.7	W	5.9	E
October	5.9	E	5.2	W	6.5	E
November	5.5	E	6.4	W	6.7	E
December	5.0	E	5.4	W	6.2	E
Annual	5.3	E	5.4	E	5.9	E

b) EXTREME (ONE-MINUTE) WINDS IN THE BEAUFORT SEA AREA BY MONTH FOR POINT BARROW, PRUDHOE BAY AND BARTER ISLAND

Month	Barrow Mean Speed (m/s)	Barrow Direction	Prudhoe Bay Speed (m/s)	Prudhoe Bay Direction	Barter Island Speed (m/s)	Barter Island Direction
January	22	E	23	W	36	W
February	21	E	17	W	28	W
March	26	W	17	ESE	34	W
April	18	WSW	16	W	23	W
May	17	WSW	15	E	25	W
June	16	SW	20	E	17	W
July	16	SW	14	WNW	18	WSW
August	16	SW	22	W	20	W
September	20	NW	21	E	35	W
October	25	W	23	ENE	26	W
November	24	W	18	E	36	W
December	25	WSW	26	W	32	W
Maximum	26	W	26	W	36	W

(FROM U.S. NATIONAL CENTER AND U.S. NATIONAL WEATHER SERVICE RECORDS)

Table 11

WIND SPEED DATA BY MONTH FOR POINT BARROW AND BARTER ISLAND
(FROM BILLELO, 1973)

Mean windspeed (m/s) and direction, Northern Hemisphere

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Barrow													
mean speed (30)	5.7	5.8	5.6	5.9	6.1	5.9	6.1	6.5	7.1	7.2	6.4	5.6	6.2
prevailing direction (7)	ESE	ENE	NE	E	NE	E	SW	E	ENE	NE	NE	ENE	NE
fastest mile (30)	56	51	48	52	43	38	41	47	56	51	63	70	70
direction (9)	E	SW			SW	W		E	W		W	W	W
Barter Island													
mean speed (7)	7.6	7.8	6.0	6.5	6.1	5.7	5.3	5.7	6.6	7.6	7.7	6.1	6.5
prevailing direction (7)	W	W	W	ENE	E	ENE	ENE	E	E	E	ENE	ENE	ENE

() Number of years of record

STORM SURGES

12.0 STORM SURGES

Storm surges may occur with little or no warning. They are caused by the wind pushing water towards the coastline thus causing a rise in sea level at the coast. This rise in sea level can cause severe flooding along a coastline. A brief description of storm surges was presented in section A. This section provides a more detailed study of storm surge events and a practical method for estimating how high the sea level might rise and therefore how severe the flooding might be.

Surges are highest when there is little or no ice (open water) over the ocean. Intensive storms can produce 12-foot (3.7 meters) surges over almost any portion of the western and northern Alaska coasts. This seems to be the upper limit of surges in most places. In ice-covered seas the surge is usually less than 3 feet ($\sim$1 meter). A hazard associated with ice-covered surges is the flooding of shorefast or bottomfast ice as the rising water comes through the cracks in the ice. Another hazard is ice push-up, which occurs when floating ice rises above shorefast ice and is pushed on-shore by wind or current forces.

Finally, there is the condition were the sea is ice covered, but the ice is relatively thin or unconsolidated. Some storms are capable of obliterating thin ice and thus creating an open water condition. Surges have exceeded 4 feet with these situations.

Autumn is the season for most storm surge flooding along the Beaufort Sea coast. The most likely storm for a surge is one moving from west to east well offshore with the surge being caused by the west to northwest winds in the southwest quadrant of the storm.

The two worst recorded cases of coastal flooding were caused by fall storms. One, in October 1963 (Section E, Case #4), had a surge of 12 feet (3.7 meters) in Barrow and lesser surges from Point Lay to Barter Island. The other, in September 1970 (Section E, Case #6), was judged to be as high as any previous storm as determined by driftwood lines. The elevation of the highest driftwood line varied from 4.5 to 11.2 feet (1.4 to 3.4 meters) above sea level. The variation of height is partially due to differences in exposure. Since the onshore winds during the storm were from the west, eastern shores of stream mouths, bays, etc., had higher surges than western shores. Figure 56 shows the paths of meteorological systems which have caused large storm surge occurrences. Documentation of some of these events as well as others is provided by Wise et al., 1981 (Section E).

12.1 RAPID MANUAL FORECAST FOR THE BEAUFORT SEA COAST

1. Favorable wind direction for surge formation measuring clockwise: 270 to 020 (°T).

2. If the wind is from a favorable direction determine the following from meteorological forecasts:

a. The number of hours the coastal area will be subjected to the favorable winds. The wind direction and speed should be reasonably constant and not vary past the following limits:

(1) The wind direction or orientation of the isobars does not change direction at a rate greater than 15° per 180 nautical miles and the total changes does not exceed 30°.

(2) The wind speed does not vary more than 20 percent from the average wind speed in the area of the direction fetch being considered. Example: average wind is 40; acceptable range is 32 to 48.

3. Using the wind speed compute the surge height from Figure 55. The surge height is then adjusted for duration of wind speed, ice cover and barometric pressure.

a. If wind speed duration is less than:

(1) 3 hours reduce surge by 60 percent
(2) 6 hours reduce surge by 40 percent
(3) 9 hours reduce surge by 20 percent
(4) 12 hours reduce surge by 10 percent
(5) 12+ hours no reduction

b. If ice cover is less than:

(1) 1.5 tenths no reduction
(2) 3.0 tenths reduce surge by 20 percent (cumulative to above)
(3) 5.0 tenths reduce surge by 50 percent (cumulative)
(4) 10.0 tenths reduce surge by 75 percent (cumulative)
(5) Surges to 3 feet with 10 tenths ice cover have been reported with ice to 3 feet thick between October and January.

c. Raise the surge height one foot for every 30 mb pressure increment below 1000 mb in surge area.

The above surge prediction method contains some subjectively derived information. Therefore it should not be used to predict an exact value of the surge height, but rather, a general estimate of the potential magnitude of a surge event.

4. Example

A possible surge condition is developing in the Prudhoe Bay region. Predicted wind is 290°T at 38 knots. Using Figure 57 the surge height is predicted to be 10 feet. Wind duration is forecast to be five hours. Reduce surge by 40 percent (10 -4 = 6). Ice cover is 4 tenths. Reduce surge by 50 percent (6 -3 = 3). Lowest pressure coincident with surge is 960 mb. Raise surge height 1.3 feet (3 +1.3 = 4.3). Estimated surge height is therefore predicted to be between 4 and 5 feet.

(1 foot = 0.3048006 m)
(1 nautical mile = 1.85326 Km)

1. 2-3 Oct, 1963, Barrow
2. 5-7 Oct 1963, Barrow
3. 15-17 Nov 1966, Barrow
4. 20-25 Sep 1968, Barrow
5. 26-27 Aug 1975, Icy Cape
6. 17 Aug 1975, Icy Cape, negative surge
7. 8-12 Oct 1972, Point Lay
8. 25-26 Oct 1969, Barrow

Two additional surges not on the map: one with a low center 177° 178°N, and another caused by a large persistent high pressure area centered north and east of the area.

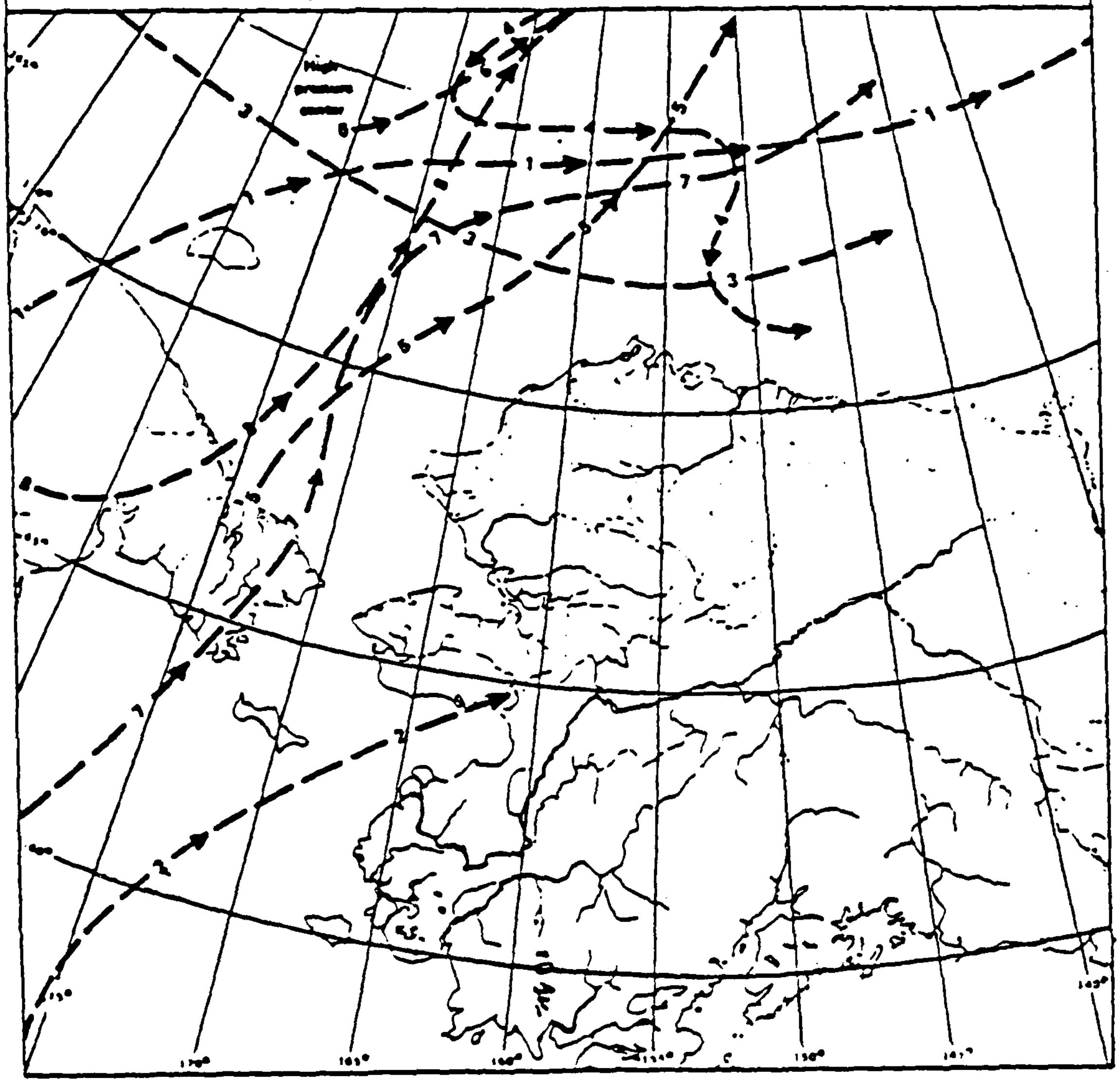
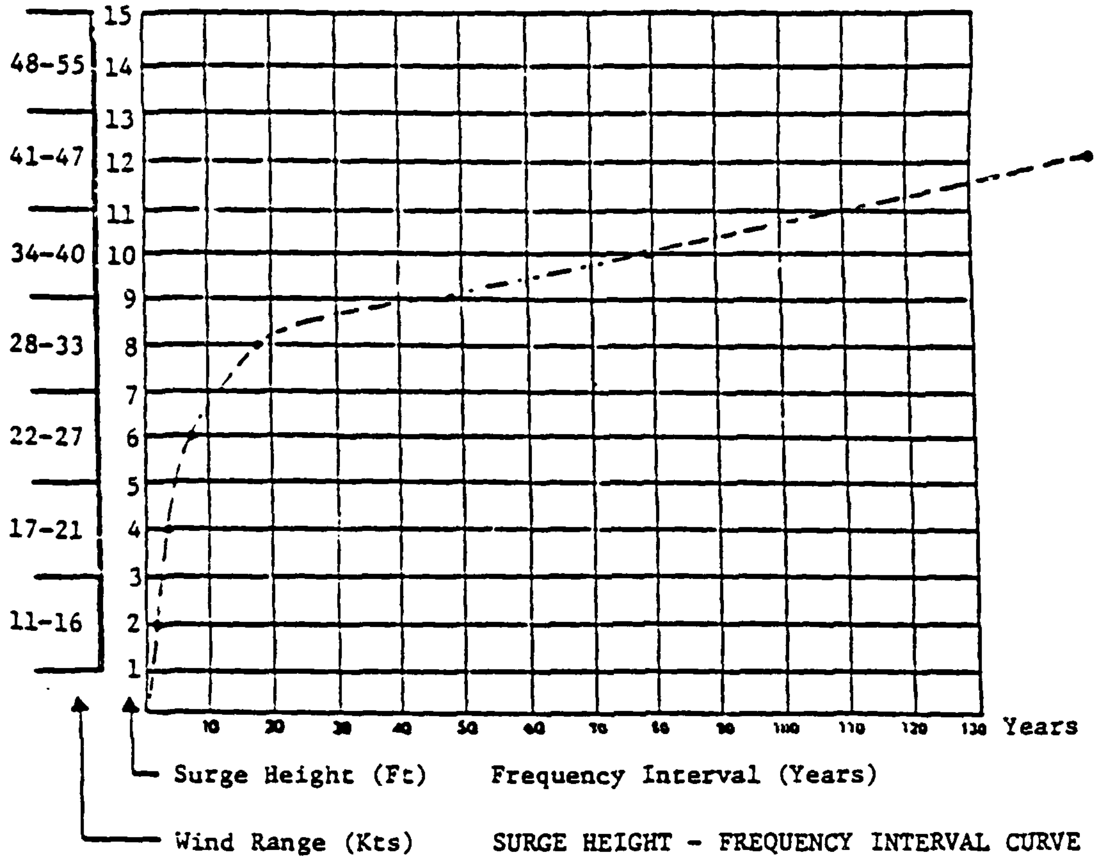


FIGURE 56 - PATHS OF METEOROLOGICAL SYSTEMS THAT HAVE CAUSED STORM SURGES (FROM BROWER, ET AL., 1977)



(1 foot = 0.3048006 m)
(1 knot = 0.5148 m/s)

FIGURE 57 - CURVE OF SURGE HEIGHT VS FREQUENCY OF OCCURRENCE FOR STORM SURGES IN THE BEAUFORT SEA

WAVES

13.0 WAVES

Wave action along the North Alaskan coast is inhibited by the presence of the pack ice and floating ice during periods of open water. The pack ice during the summer and fall months may vary from only a few kilometers to 100 kilometers offshore depending on meteorologic conditions. The pack ice reduces the open water fetch and floating ice on open water areas reduces the development of waves. The surface winds determine the prevailing direction of the seas.

When ice conditions provide an appreciable fetch, the generally small sea height conditions can be surpassed (tables 12-14). For the Western Beaufort Sea area waves of greater than 30 feet (9.1 meters) were recorded for winds from the east. Other wave occurrences of more than ten feet are indicated for all of the areas along the coast. However, for all these areas the tabulations of sea height versus direction indicate that over 85% of the time sea height is less than 3 feet ($\sim$1 meter). For the nearshore area of Pingok Island, Wiseman, et al. (1979), found that the most common nearshore wave field had an energy peak at periods between 2 and 3 seconds and a significant wave height of 20 to 30 cm. These nearshore conditions are generally true for the entire Beaufort Sea coast.

Tables 15-17 provide further information on sea height conditions in the Beaufort Sea. For the western, central and eastern areas of the coast, sea height values are provided for different wind speed groups for eight directions of the compass.

Table 18 provides estimates of maximum sustained winds, maximum significant waves, and extreme waves for various selected return periods.

Table 12

SEA HEIGHT (FT) VS DIRECTION FROM 11 JULY TO 31 OCTOBER FOR THE CENTRAL BEAUFORT SEA COAST
(FROM GATTO, 1980)
(1 foot = 0.3048006 m)

SEA HEIGHT

SEA DIRECTION	<3	3	5	6.5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	2												2	0.2
NNE	4	4											8	1.0
NE	8	1											9	1.1
ENE	32	2	2										36	4.4
E	68	23	2										94	11.5
ESE	25	9											34	4.2
SE	4	3											7	0.9
SSE	8	6											14	1.7
S	5	1											6	0.7
SSW	3			2									5	0.6
SW	7												7	0.9
WSW	2	3											5	0.6
W	34	7	4										45	5.5
WNW	36	10	3	4									63	7.7
NW	37	6		3	1		1						48	5.9
NNW	5			2									7	0.9
CALM	428												428	52.3
C -15														
C +15														
TOTAL	706	77	12	21	1		1						818	
%	86.3	9.4	1.5	2.6	0.1		0.1							100.0

Table 13

SEA HEIGHT (FT) VS DIRECTION FROM 11 JULY TO 31 OCTOBER FOR THE EASTERN BEAUFORT SEA COAST
(FROM GATTO, 1980)
(1 foot = 0.3048006 m)

SEA HEIGHT

SEA DIRECTION	< 3	3	5	6.5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	4	1											5	0.5
NNE	4												4	0.4
NE	24	8	2										34	3.2
ENE	48	7	3										68	6.4
E	57	45	9										111	10.4
ESE	16	3											19	1.8
SE	4	8	2						1				15	1.4
SSE	1												1	0.1
S	3								3				6	0.6
SSW	2												2	0.2
SW	8	1											9	0.8
WSW	6												6	0.6
W	33	6	2	2									43	4.0
WNW	21	7											28	2.6
NW	14	5											19	1.8
NNW	2												2	0.2
CALM	696												696	66.2
C -15														
C +15														
TOTAL	953	91	18	2					4				1048	
%	89.2	8.5	1.7	0.2					0.4					100 / 100.0

Table 14

SEA HEIGHT (FT) VS DIRECTION FROM 1 JULY to 20 NOVEMBER FOR THE WESTERN BEAUFORT SEA COAST

(FROM GATTO, 1980)

(1 foot = 0.3048006 m)

SEA HEIGHT

SEA DIRECTION	<3	3	5	6 5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	39	12											51	2.1
NNE	38	17			2								57	2.4
NE	108	8	2				1						119	4.9
ENE	141	28	5										174	7.2
E	174	29	2		2							2	211	8.7
ESE	53	5											58	2.4
SE	15	1		1									17	0.7
SSE	18	2											20	0.8
S	4	1											5	0.2
SSW	10	2											12	0.5
SW	13	3											18	0.7
WSW	31	4	2										37	1.5
W	71	16	5	2	2								96	4.0
WNW	35	19	25	5	1				1				86	3.7
NW	28	10	3	4									47	2.0
NNW	29	8											37	1.5
CALM	1370												1370	56.7
C -15														
C +15														
TOTAL	2178	168	44	14	7		1		1			2	2415	
%	90.2	7.0	1.8	0.6	0.3		0.0		0.0			0.1		1000 / 1000

TABLE 15

WIND SPEED AND DIRECTION VS. SEA HEIGHT FROM 11 JULY to 31 OCTOBER
FOR THE CENTRAL BEAUFORT SEA COAST
(FROM GATTO, 1980)

(1 knot = 0.5148 m/s)
(1 foot = 0.3048006 m)

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N								NNE & NE								ENE & E								ESE & SE							
	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL
2	2	26	6	3	3			40	11	45	40	29	3			126	12	64	83	96	21	1		277	6	19	32	23	3			83
3			2	12				14		2	2	30	18	1	1	66												8	3			11
5											1		2			3				4	3	2		9				2	2			4
6.5													1			1																
8																																
9.5																																
11																																
13																																
14																	2	1						3					1			1
16																																
17.5																																
20+																																
TOTAL	2	26	6	3	3			40	11	45	43	41	4			144	14	67	85	130	42	4	1	333	6	19	32	33	9			99
%	0.2	2.4	0.6	0.3	0.3			3.7	1.0	4.2	4.0	3.8	0.4			13.4	1.3	6.3	7.9	12.1	3.9	0.4	0.1	31.1	0.6	1.8	3.0	3.1	0.8			9.2

SEA HEIGHT (FEET)	SSE & S								SSW & SW								WSW & W								WNW & NW								TOTAL	%
	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 3	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL		
2	2	20	8	3				33	6	15	12	7	8			48	79	41	50	35	16			221	3	36	34	43	6	2		126	956	89.3
3				1				1					1			1			1	4	1			6		3	6	1	1	1		12	91	8.5
5																				1	1			2									18	1.7
6.5																				1				1									2	0.2
8																																		
9.5																																		
11																																		
13																																		
14																																	4	0.4
16																																		
17.5																																		
20+																																		
TOTAL	2	20	8	4				34	6	15	12	7	9			49	79	41	51	41	18			230	3	39	40	45	7	3		138	1071	
%	0.2	1.9	0.7	0.4				3.2	0.6	1.4	1.1	0.7	0.8			4.6	7.4	3.8	4.8	3.8	1.7			21.5	0.3	3.6	3.7	4.2	0.7	0.3		12.9		100.0 100.1

TABLE 16

WIND SPEED AND DIRECTION VS. SEA HEIGHT FROM 11 JULY to 31 OCTOBER
FROM THE EASTERN BEAUFORT SEA COAST
(FROM GATTO, 1980)

(1 knot = 0.5148 m/s)
(1 foot = 0.3048006 m)

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N								NNE & NE								ENE & E								ESE & SE							
	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL
1		18	9	13	2			42		16	13	17				46	5	46	93	87	14			240	1	16	26	33	5	1	1	83
3		2	2					4		1	2	1				4			2	19	10	2		33			5	2	1			7
5																				1	2			3					1			1
6.5				1				1																								
8																																
9.5																																
11			1					1																								
13																																
14																																
16																																
17.5																																
20+																																
TOTAL		20	12	16	2			48		17	15	18				50	5	41	95	102	26	2		276	1	16	28	35	8	1	1	91
%		1.4	1.5	1.7	0.2			3.8		2.1	1.8	2.2				6.1	0.6	5.0	11.6	13.3	3.2	0.2		33.6	0.1	1.9	3.4	4.3	1.1	0.1	0.1	11.1

SEA HEIGHT (FEET)	SSE & S								SSW & SW								WSW & W								WNW & NW									
	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	TOTAL	%
	2	11	10	6				29	1	8	11	4	1			25	52	25	18	20	5		1	121	2	33	40	37	11			123	709	86.4
				2	2			4												3	3			6		1	4	6	8			19	77	9.4
				1				1												2				2				4	1			5	12	1.5
													2			2				2	2			4				2	10	2		14	21	2.6
																												1				1	1	0.1
																																	1	0.1
	2	11	10	9	2			34	1	8	11	4	3			27	52	25	18	27	10		1	133	2	34	44	50	30	2		162	821	
	0.2	1.3	1.2	1.1	0.2			4.1	0.1	1.0	1.3	0.5	0.4			3.3	6.2	3.0	2.2	3.3	1.2		0.1	16.1	0.2	4.1	5.4	6.1	3.7	0.2		19.7		99.9 100

TABLE 17

WIND SPEED AND DIRECTION VS. SEA HEIGHT FROM 1 JULY TO 20 NOVEMBER
FOR THE WESTERN BEAUFORT SEA COAST
(FROM GATTO, 1980)

(1 knot = 0.5148 m/s)
(1 foot = 0.3048006 m)

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N								NNE & NE								ENE & E								ESE & SE							
	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL
2	11	54	56	44	11	2		178	8	87	107	92	50	2		346	14	104	181	207	113	9		628	16	62	82	48	11			219
3			3	8	4			19		2	2	13	14	4		33			3	13	20	7		43	1		5	5	6	1		18
5				1	2			3				2				2			1	1	1	2		5								
6.5						2		2														1		1								
8													2			2			2					2								
9.5																																
11												1				1																
13																																
14																																
16																																
17.5																																
20+																																
TOTAL	11	54	57	52	15	4		198	8	89	109	106	66	6		384	14	104	187	221	134	19		681	17	62	87	53	17	1		230
%	0.5	2.2	2.4	2.1	0.6	0.2		8.2	0.3	3.7	4.5	4.4	2.7	0.2		15.9	0.6	4.3	7.7	9.1	5.5	0.8		28.1	0.7	2.6	3.6	2.2	0.7	0.0		9.9

SEA HEIGHT (FEET)	SSE & S								SSW & SW								WSW & W								WNW & NW								TOTAL	%
	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL	0 - 2	3 - 7	8 - 12	13 - 20	21 - 30	31 - 40	40+	TOTAL		
2	10	51	46	27	6			140	6	27	46	58	6			143	83	56	85	89	19			332	70	54	66	48	9			197	2183	90.2
3			1	5	1			7			1	4				5	1	1	2	12	9			25				12	9	1		22	168	6.9
5						1		1					2			2					5	3		8				1	17	4		22	45	1.9
6.5																													6	5		11	14	0.6
8																					2			2						1		1	7	0.3
9.5																																		
11																																	1	0.0
13																																		
14																			1					1									1	0.0
16																																		
17.5																																		
20+																																	2	0.1
TOTAL	10	51	47	32	7	1		148	6	27	47	62	8			150	84	57	88	101	35	3		368	70	54	66	61	41	11		253	2421	
%	0.4	2.1	1.9	1.3	0.3	0.0		6.1	0.2	1.1	1.9	2.6	0.3			6.2	3.5	2.4	3.6	4.2	1.4	0.1		15.2	2.9	2.2	2.7	2.5	1.7	1.2		10.5		100.0

TABLE 18

ANNUAL MAXIMUM WINDS AND WAVES FOR SELECTED RETURN PERIODS

Return periods for maximum sustained winds and for maximum significant and extreme wave heights are presented in tabular form for the Beaufort Sea coast. Sustained winds are winds averaged over a period of one minute; the significant wave height is the average height of the highest one third of all waves (sea and swell) in view and the extreme wave height is an empirical estimate of 1.8 times the significant wave height. The return period (years) is statistically derived from empirical observations. It estimates how often an extreme event may occur in a particular area. For example, on the average the Beaufort coast can expect annual maximum sustained wind speed to exceed 81 knots once in 100 years.

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave meters (feet)
5	57	10.0 (33)	18.0 (59)
10	62	11.0 (37)	20.5 (67)
25	69	13.0 (43)	24.0 (78)
50	75	15.0 (49)	27.0 (88)
100	81	17.0 (55)	30.0 (99)

SECTION C
ICE

14.0. ICE ZONES

Three ice zones can be broadly defined for the southern Beaufort Sea.

1. Fast ice zone - consists of seasonal ice which is an extension of the land, because it generally remains immobile during the winter. Its extension seaward varies but typically progresses to the 20 meter depth contour by late winter. The ice is generally two meters thick.

2. Seasonal pack ice zone - begins at the edge of the fast ice and continues out 100 to 200 km. There are often strong shear forces within this ice zone. It is mobile and often contains a large percentage of first year ice. In this zone, the undeformed areas of ice have an average thickness of approximately 2 meters.

3. Polar pack ice zone - mainly composed of thick multi-year floes. This zone generally lies beyond the continental shelf. Approximate ice thickness of the general terrain of old multi-year floes is 2 to 4 meters.

SHORE FAST ICE

15.1 ANNUAL ICE CYCLE WITHIN THE NEARSHORE AREA OF THE BEAUFORT SEA (AVERAGE CONDITIONS)

Time	Event
Late September to early October	New ice begins to form in open water. Ice forms first adjacent to rivers and in coastal lagoons. (During severe ice seasons this process can begin as early as late August.)
Mid to late October	The landfast ice sheet has formed and is continuous. Areas of the ice are unstable because of the thinness of the ice (particularly north of the barrier islands).
November to February	The landfast ice area has thickened and become more stable, particularly inside the barrier islands. Some modifications of the ice sheet occur due to ridging, incursions of older pack ice north of the barrier islands, and grounding of ice masses as they are driven ashore by the winds.
March to May	Ice has generally reached its greatest thickness. Ice has its most stable period during this time.
Late May to early June	Warming trend causes breakup of rivers and over-flooding of ice by the rivers in the nearshore zone.
Early to late June	Melt ponds begin to form on the ice. The ice begins to lose thickness and therefore weakens. Toward the end of the period open water areas begin to occur. These areas are generally along the coast and around the barrier islands, particularly the southern sides. Cracks in the ice can be found both north and south of the barrier islands.
June to August	Breakup of ice sheet continues. Significant open water occurs within the barrier islands by mid to late July.
August to September	Generally open water within the barrier islands. Some ice masses remain within the barrier island during severe ice years. Open water north of the barrier island is dependent on the north-south migration of the pack ice. Refreezing occurs.

15.2 FREEZING AND BREAKUP OF NEARSHORE ICE

Table 19 provides data on freezing and breakup of the nearshore ice field at Point Barrow and Barter Island. As can be seen, yearly freezeup may occur at Barter Island at any time between 20 September and 25 October and at Point Barrow at any time between 23 September and 19 December. Similarly, breakup has occurred at Point Barrow as early as 15 June and as late as 22 August, and at Barter Island from 22 July to 14 August. Freezeup and breakup are at present unpredictable parameters.

Table 19

FREEZEUP AND BREAKUP DATES OF FAST ICE FOR BARTER ISLAND AND POINT BARROW

STATIONS	FREEZEUP				BREAKUP			
	Earliest	Latest	Average	Years Date	Earliest	Latest	Average	Years Date
BEAUFORT SEA:								
Barter Island	9/20	10/25	10/5	6	7/22	8/4	7/28	4
Point Barrow	9/3	12/19	10/1-5	26	6/15	8/22	7/17-23	24

PACK ICE

16.0 PACK ICE

In addition to the unpredictability of freeze-up and breakup is the erratic movement of the pack ice. The pack ice can be driven toward the coast at any time by a strong onshore wind. During severe ice seasons, i.e., 1975, ships can be prevented from passing east or west along the Beaufort Sea coast. During less severe seasons, the ice edge can retreat more than 50 kilometers offshore leaving a wide expanse of open water along the entire Beaufort Sea coast. Because of the sporadic nature of ice movement and growth "average ice conditions" are difficult to ascertain. However, Brower et al. (1977) prepared a comprehensive climatic atlas of the outer continental shelf waters and coastal regions of Alaska. From their work, diagrams of the extreme northern latitude and extreme southern latitude of the pack ice edge can be shown for the period 1 July to 31 October (figures 58-61). Additionally, the mean location of the ice edge has been extracted for this same period (figures 62-65).

Satellite imagery has provided a method of obtaining more detailed information of sea ice distribution. Barnes et al. (1976) used four years of Landsat imagery to compile statistics on nearshore ice concentration relative to the distance from the Alaskan coast for August, September and October (figures 66-68). The lines indicate distance offshore in nautical miles.

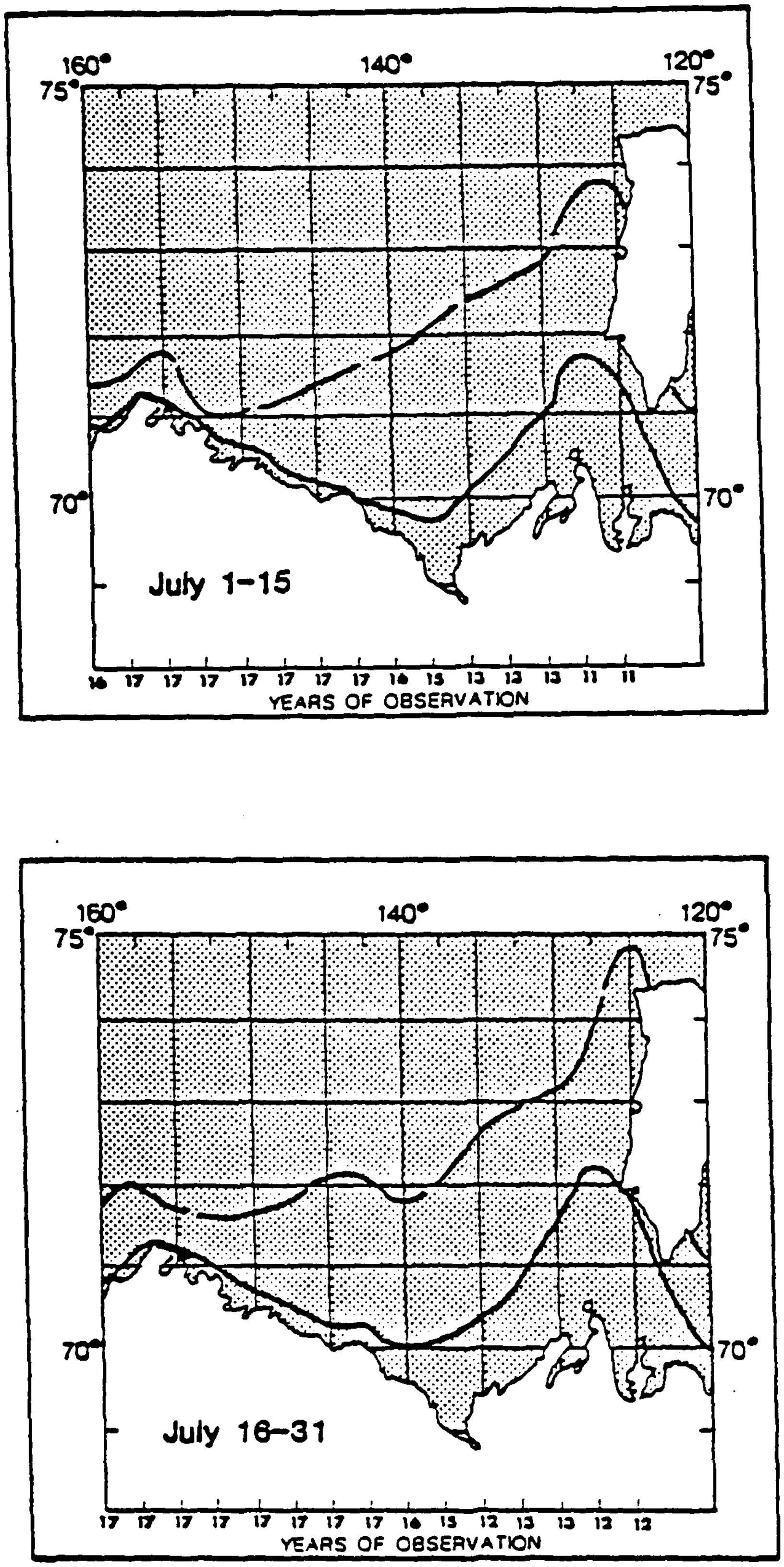


FIGURE 58 - EXTREME NORTHERN AND EXTREME SOUTHERN LATITUDE OF THE PACK ICE EDGE - JULY

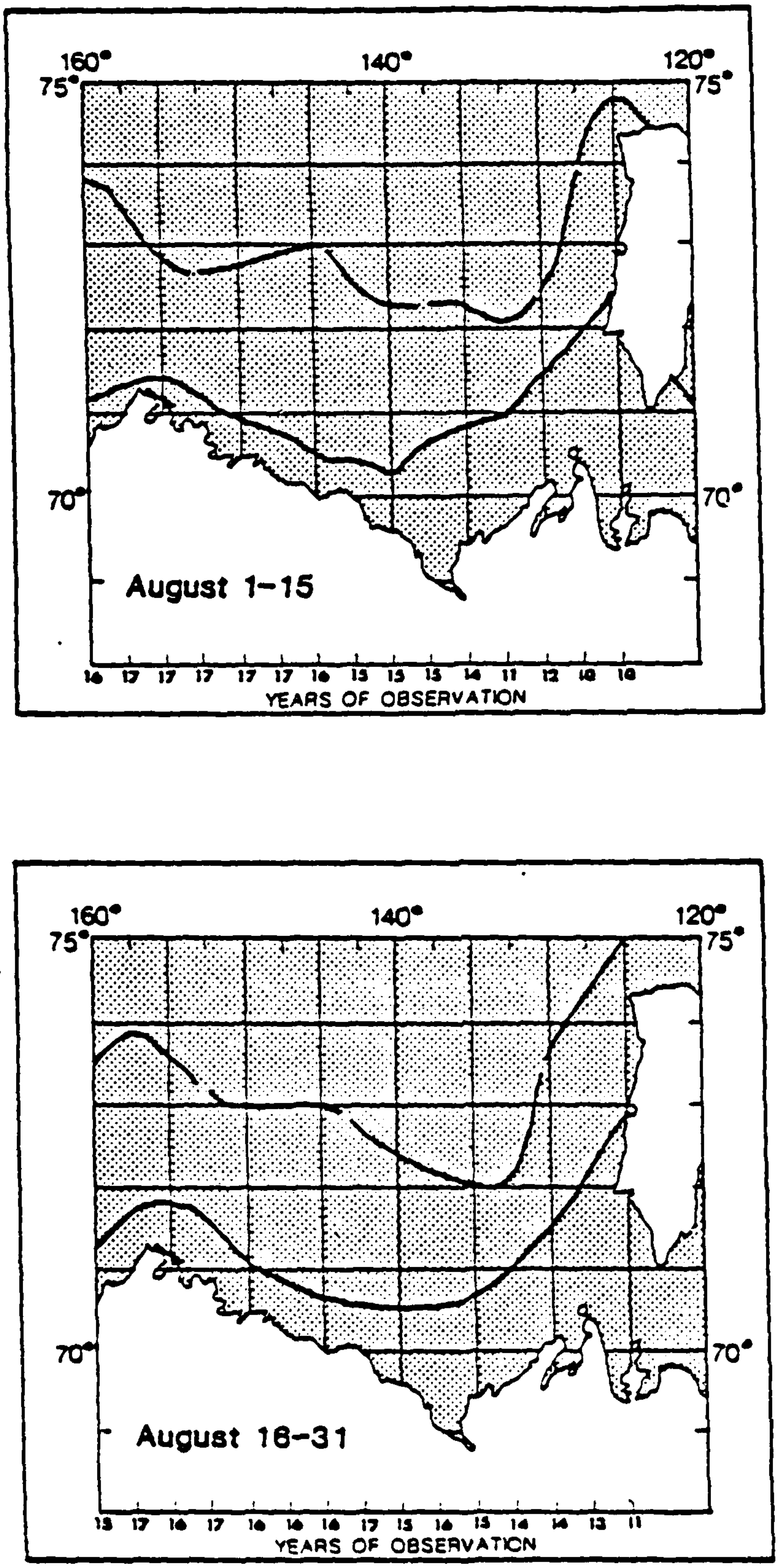
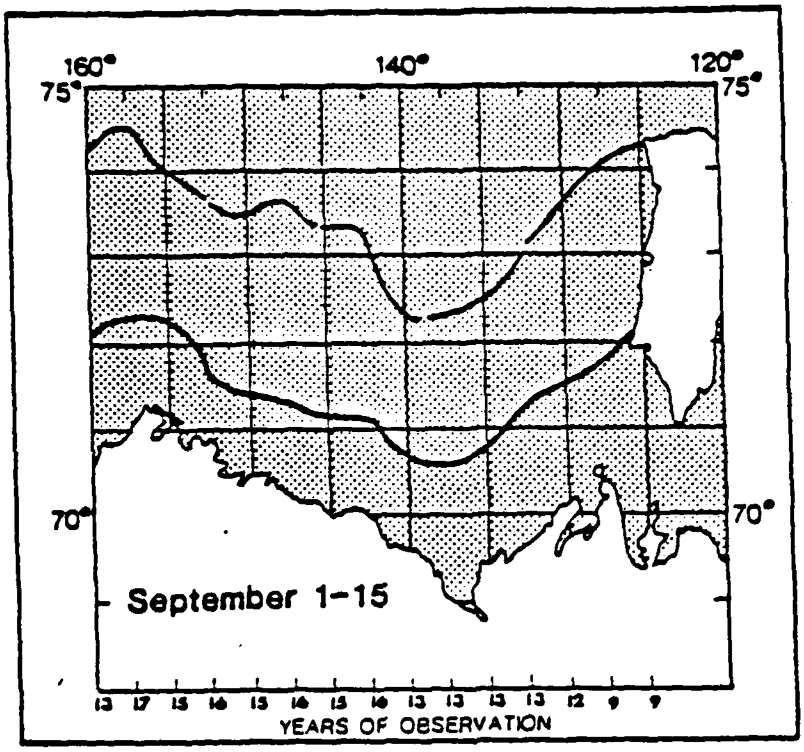


FIGURE 59 - EXTREME NORTHERN AND EXTREME SOUTHERN LATITUDE OF THE PACK ICE EDGE - AUGUST



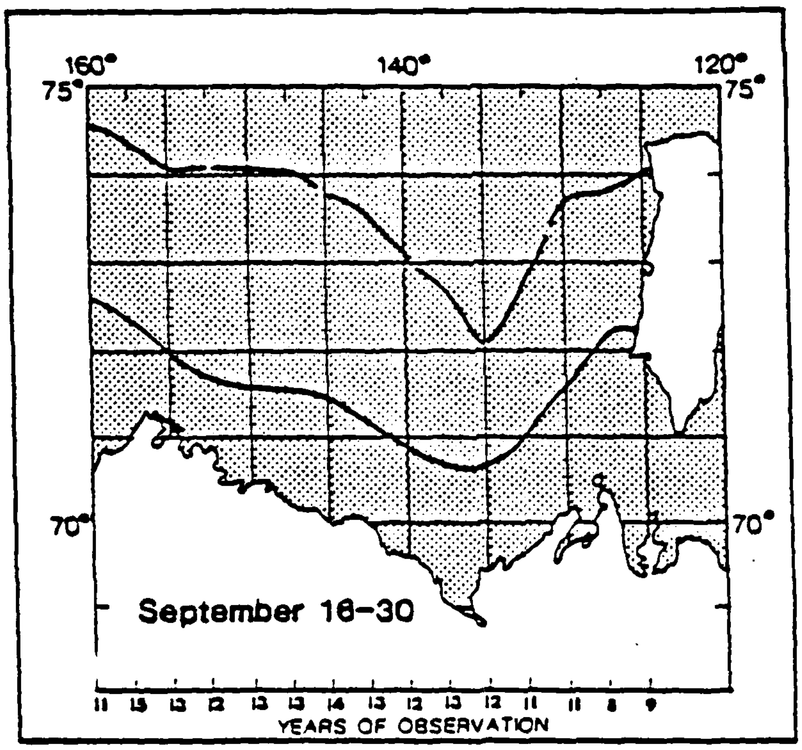
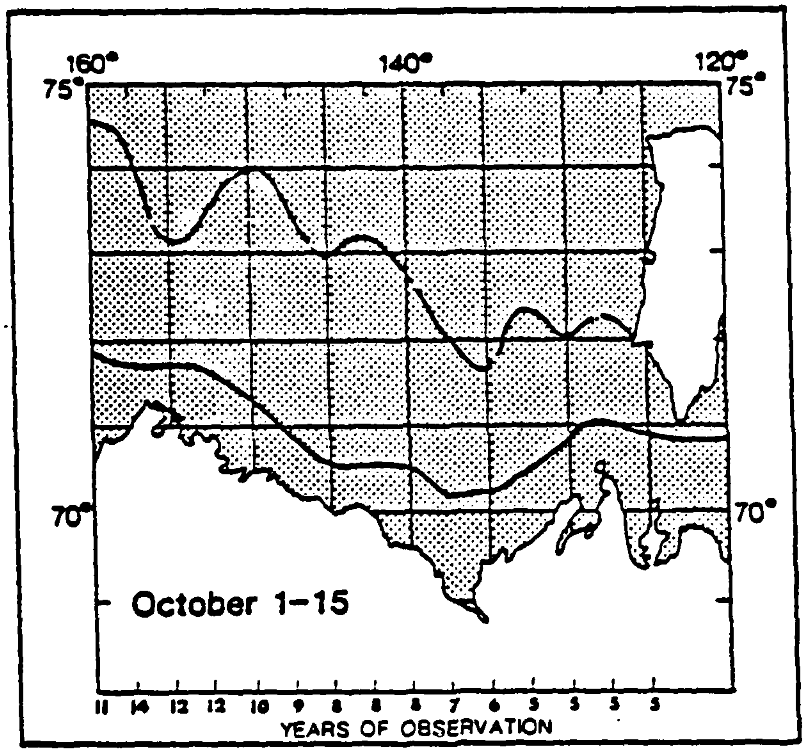


FIGURE 60 - EXTREME NORTHERN AND EXTREME SOUTHERN LATITUDE OF THE PACK ICE EDGE - SEPTEMBER



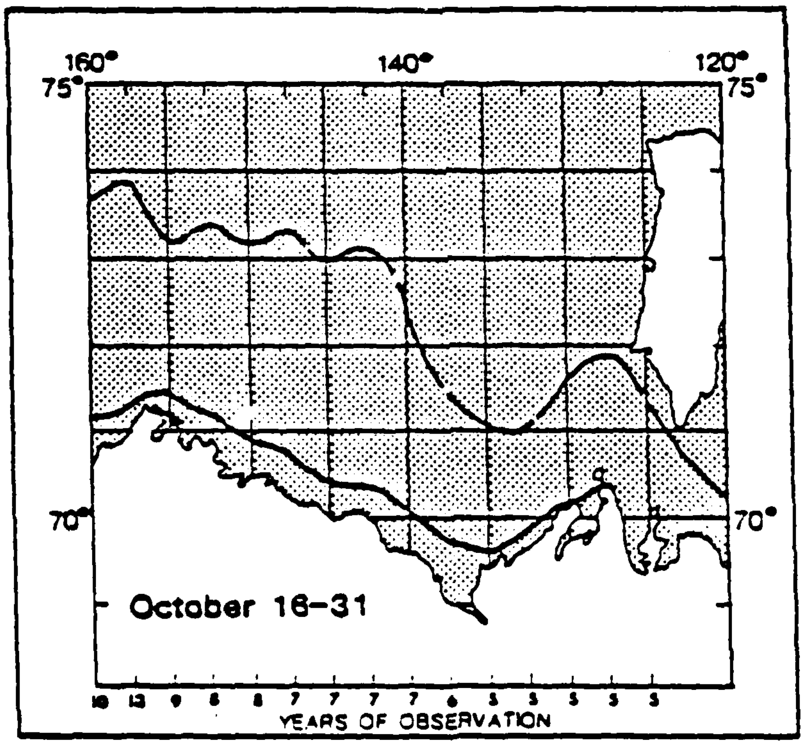
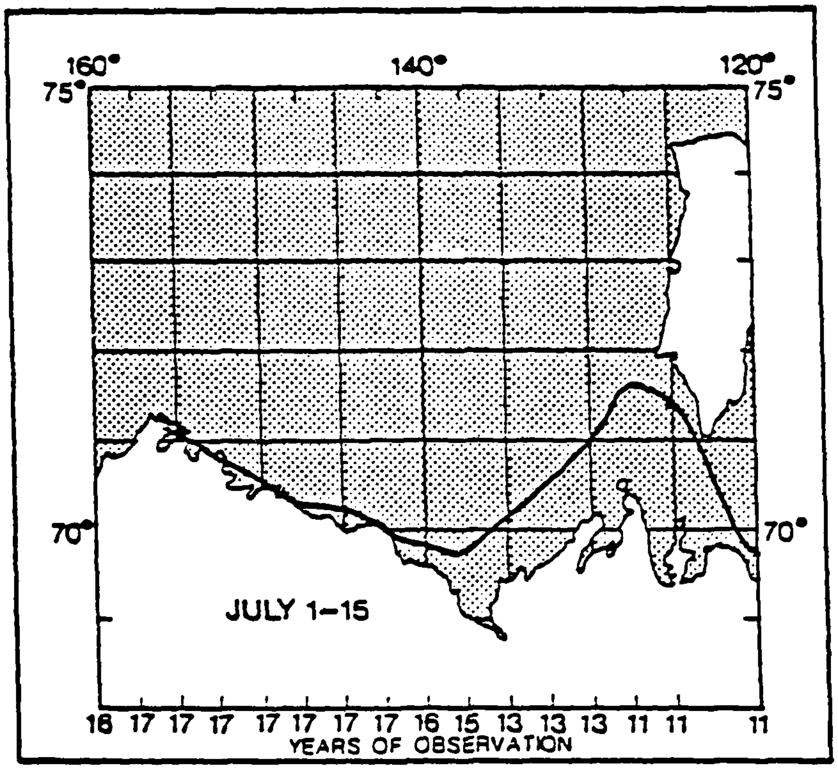


FIGURE 61 - EXTREME NORTHERN AND EXTREME SOUTHERN LATITUDE OF THE PACK ICE EDGE - OCTOBER



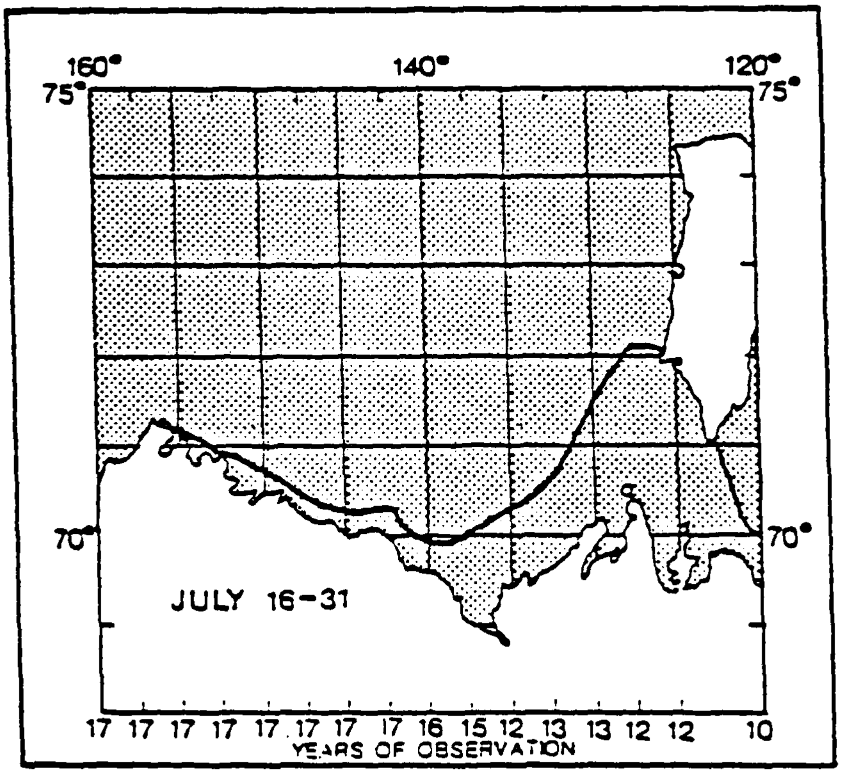
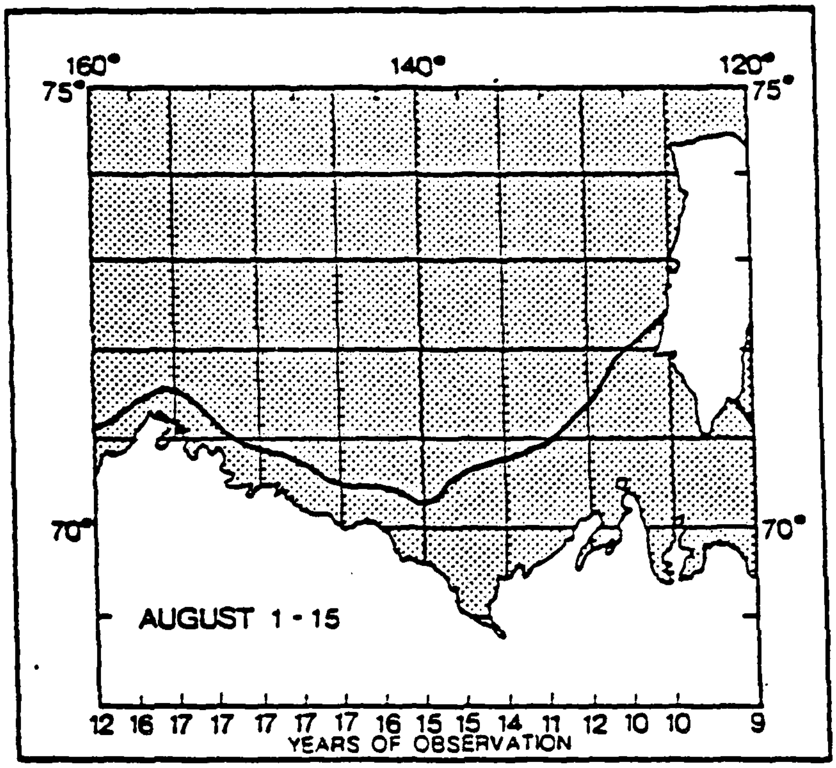


FIGURE 62 - MEAN LATITUDE OF THE PACK ICE EDGE - JULY



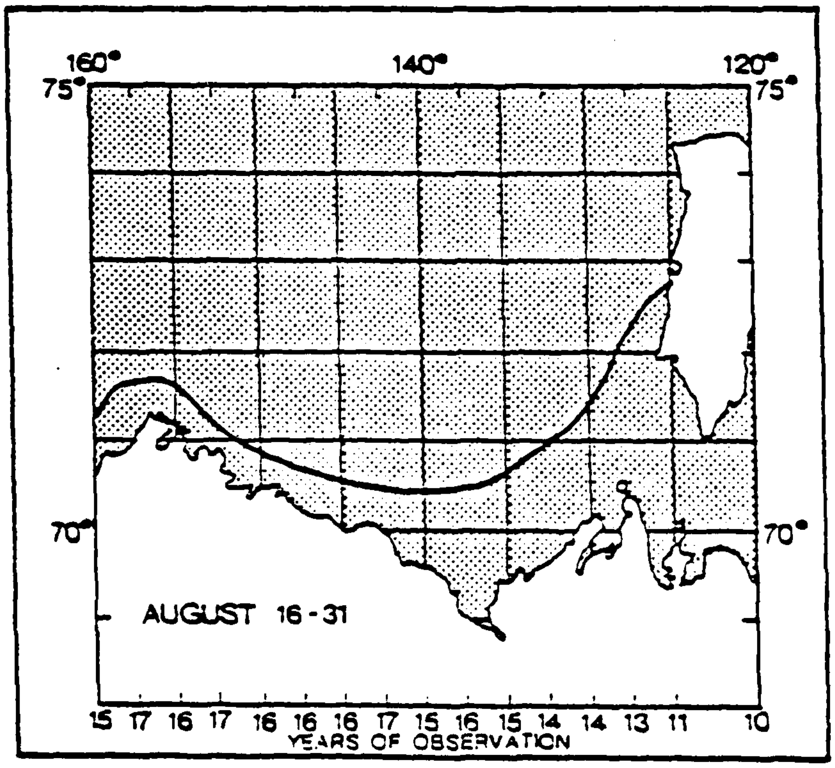
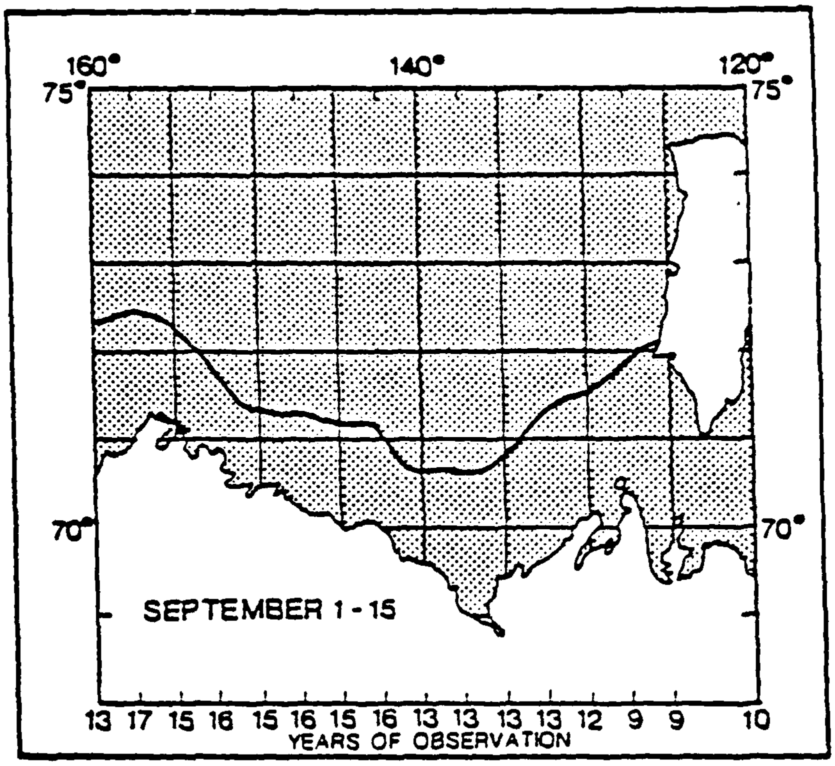


FIGURE 63 - MEAN LATITUDE OF THE PACK ICE EDGE - AUGUST



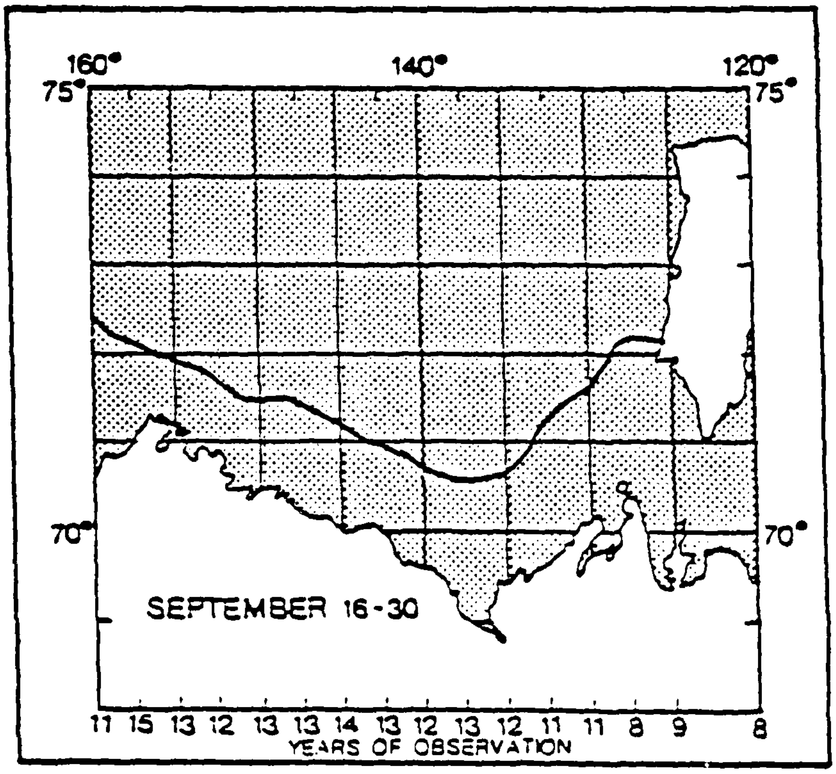


FIGURE 64 - MEAN LATITUDE OF THE PACK ICE EDGE - SEPTEMBER

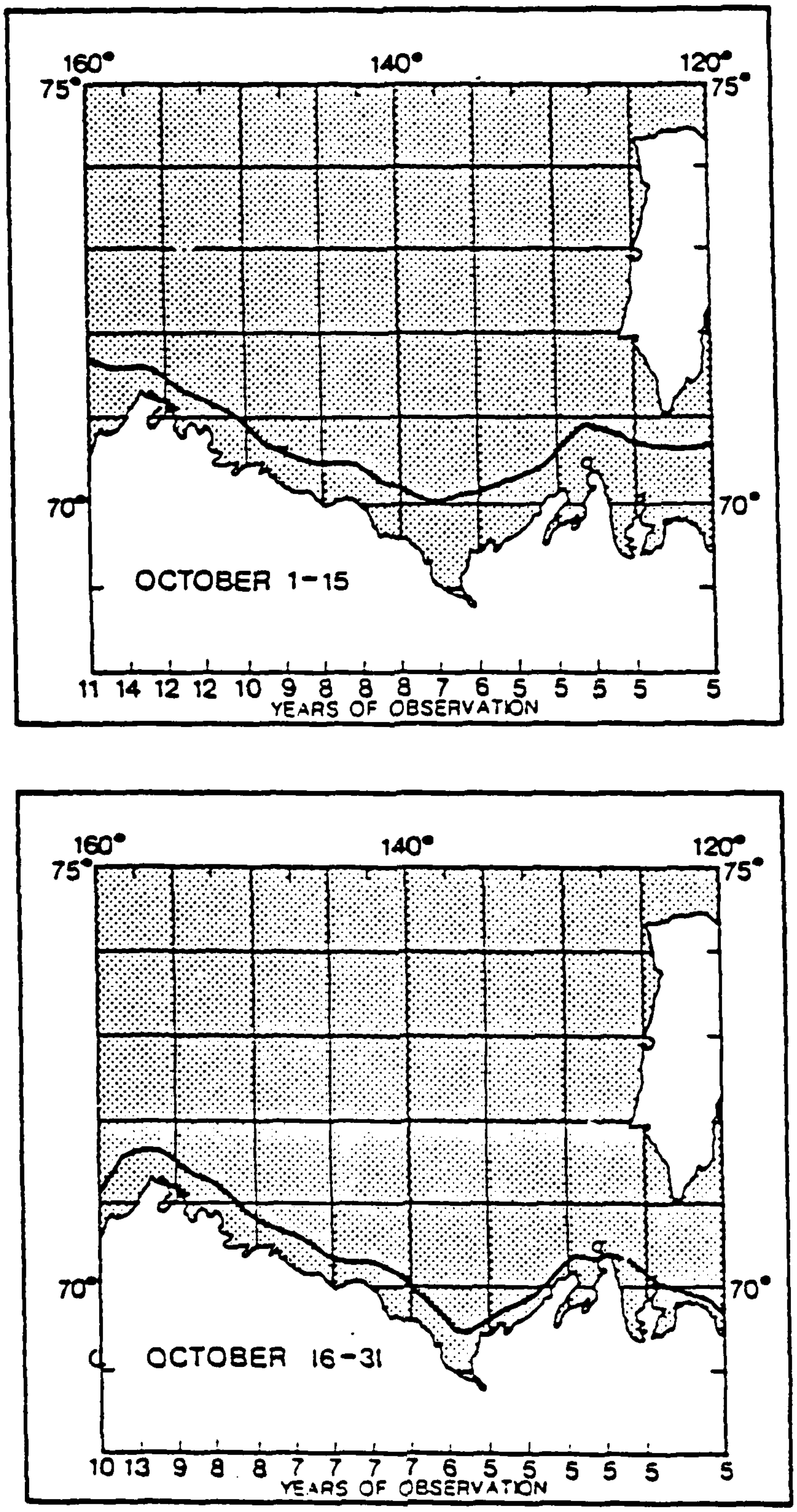


FIGURE 65 - MEAN LATITUDE OF THE PACK ICE EDGE - OCTOBER

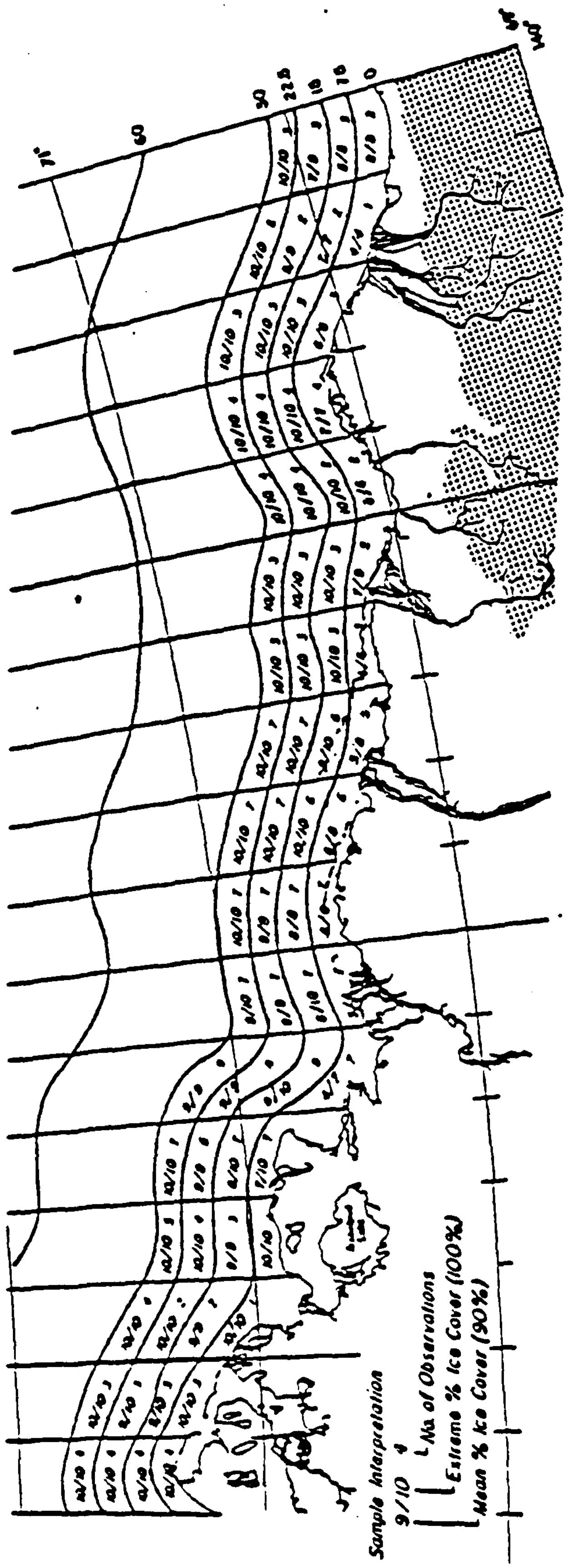


FIGURE 66 - MEAN AND EXTREME ICE COVER (%) ALONG THE BEAUFORT SEA COAST - AUGUST

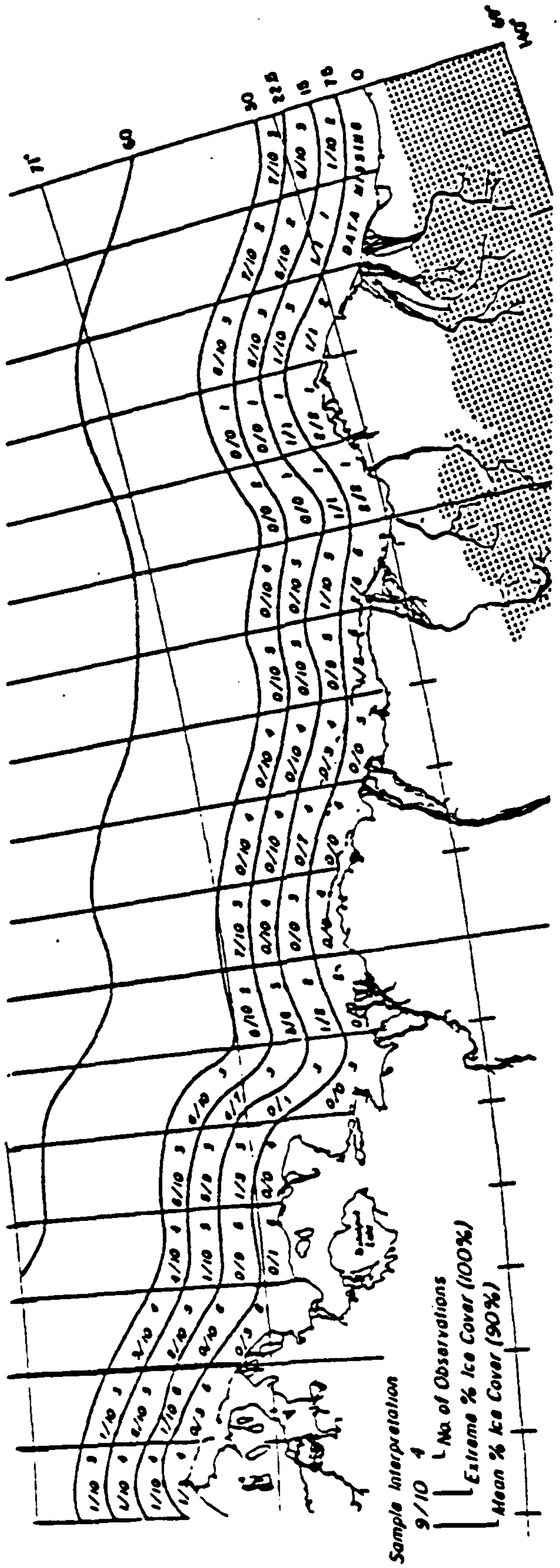


FIGURE 67 - MEAN AND EXTREME ICE COVER (%) ALONG THE BEAUFORT SEA COAST - SEPTEMBER

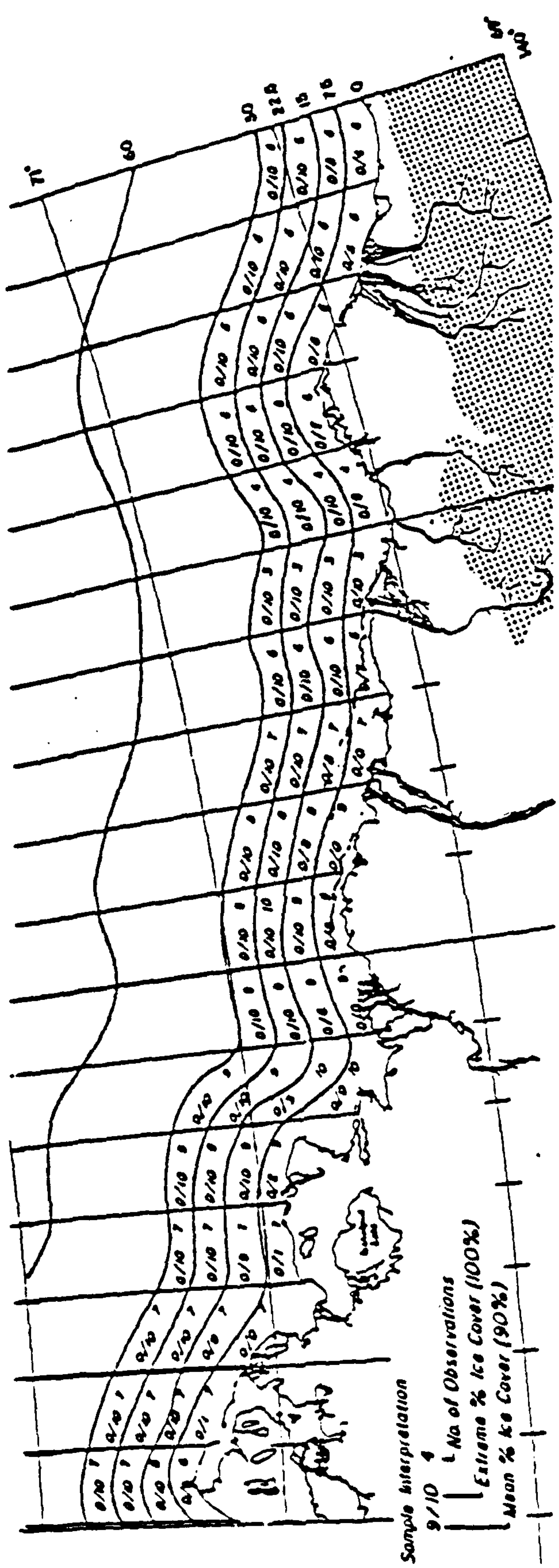


FIGURE 68 - MEAN AND EXTREME ICE COVER (%) ALONG THE BEAUFORT SEA COAST - OCTOBER

SECTION D
CLIMATOLOGY

17.0 ARCTIC CHARACTERISTICS

The term Arctic is generally associated with ideas of cold, snow, ice and high latitudes. There are a number of commonly used definitions, each valid in its own right depending on the particular function for which it was developed. Definitions may use climate, conditions, or some other variable to define the polar areas. Several definitions using climate as a criterion are:

1. The area lying north of the boundary fixed by the isotherm of 50°F (10°C) for the warmest month, or the isotherm of 14°F (minus 10°C) for the coldest month).

2. Areas having a mean annual temperature of 32°F (0°C) or below.

3. All areas where the sum of the average temperature in degrees centigrade of the warmest month plus one-tenth of the temperature of the coldest month is less than 9°C.

Regardless of the criteria used for the various definitions, there are certain characteristics common to the region. These are:

1. Short, cool summers.
2. Long, cold winters.
3. Low annual mean temperature.
4. Long periods of semi-darkness.
5. Periods of continual daylight and darkness.
6. Absence of forests.
7. Freezing in winter of lakes, rivers, bays, and parts of the sea.
8. Scant precipitation.
9. Low absolute humidity.
10. Low evaporation rate.
11. Moist soils when thawed.
12. Presence of permanently frozen ground.
13. High windchill factor.
14. High latitude position.

SUNLIGHT

18.0 SUNLIGHT

The Beaufort Sea coast receives a majority of its sunlight during the summer months. The Arctic Circle separates the area to the north which receives continuous sunlight for part or all of the summer and no sunlight during part or all of the winter (figure 69). The length of the day during the summer months is extended significantly if twilight is considered (figure 70). At latitude 70°N, twilight occurs approximately 11% of the time and therefore the yearly percentage of sunlight and twilight is 63% at the Arctic Circle latitude. These charts can be used to determine amount of darkness if a winter response to a spill is necessary.

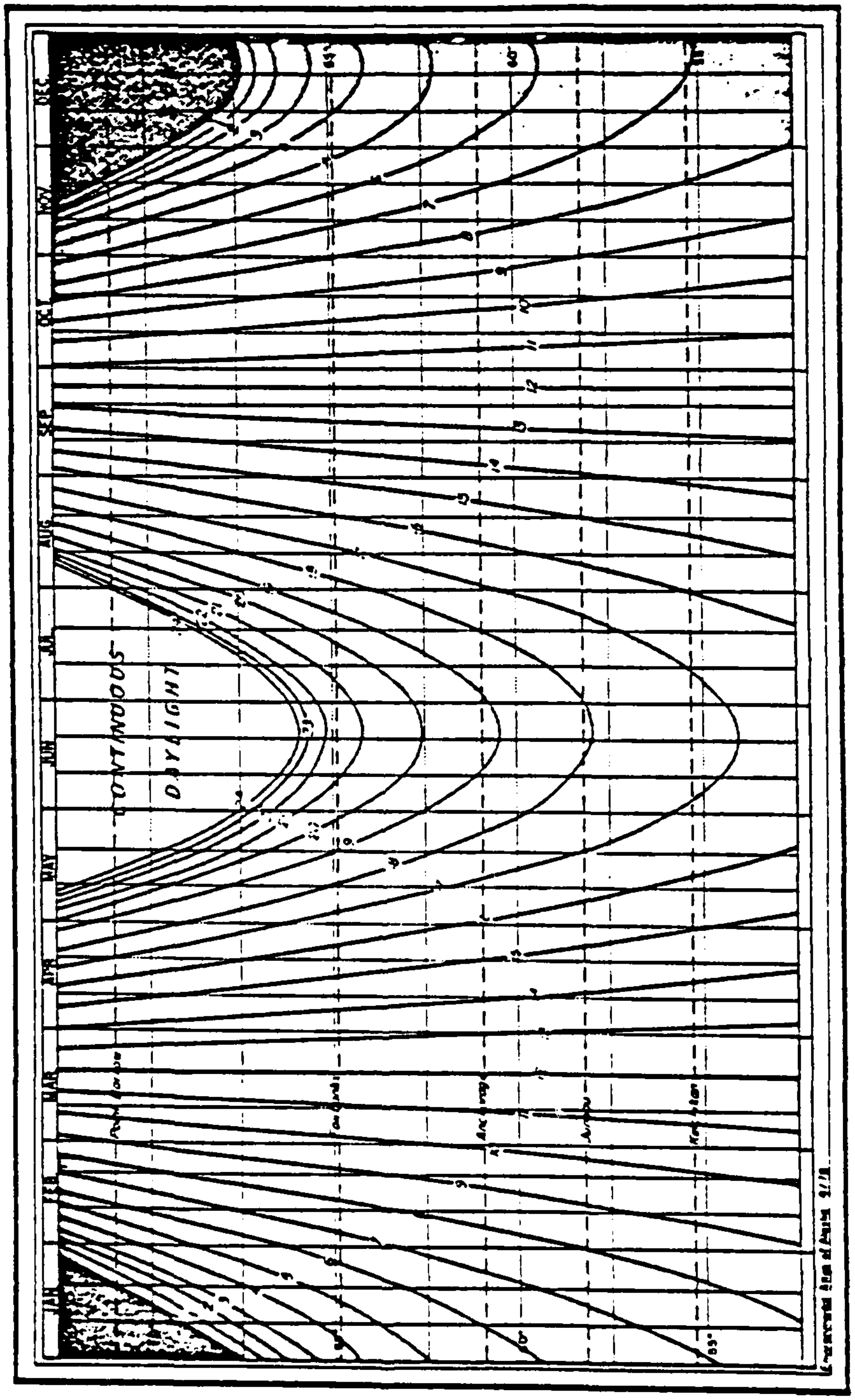


FIGURE 69 - HOURS OF CONTINUOUS SUNLIGHT ON A MONTHLY BASIS FOR NORTHERN LATITUDES (FROM HARTMAN & JOHNSON, 1978)

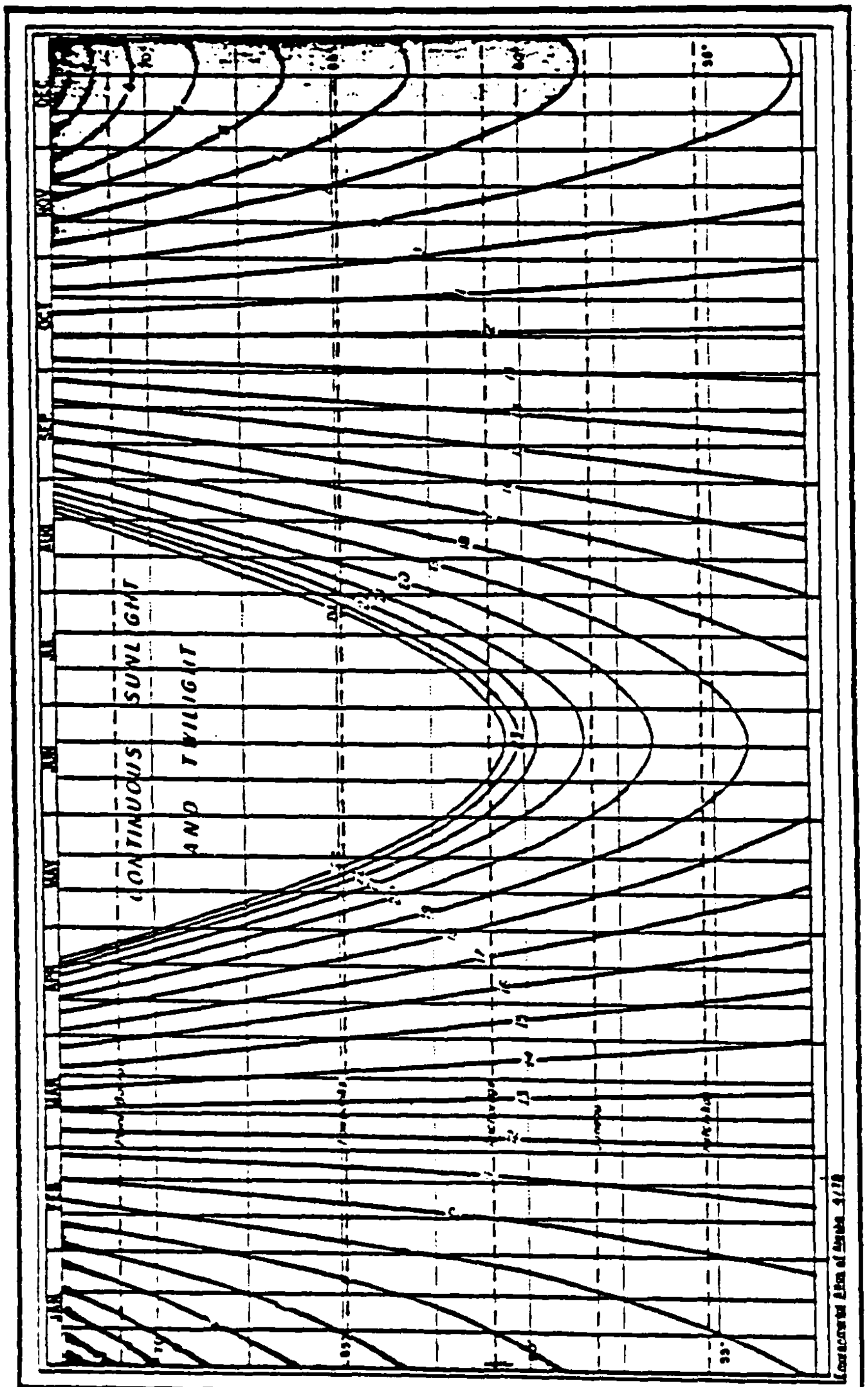


FIGURE 70 - HOURS OF CONTINUOUS SUNLIGHT AND TWILIGHT ON A MONTHLY BASIS FOR NORTHERN LATITUDES (FROM HARTMAN & JOHNSON, 1978)

TEMPERATURE

19.0 TEMPERATURE

Temperatures in the Arctic, as one might expect, are very cold most of the year. There are large differences in temperature between the interior and coastal areas. In the interior during the summer days, temperatures often climb to the mid 60's or low 70's and occasionally rise to the high 70's or low 80's. Temperatures in the 90's are also recorded on rare occasions.

The Arctic coastal regions are characterized by relatively cool, short summers. During the summer months the temperatures normally climb to the 40's or low 50's and occasionally reach the 60's. There is almost no growing season along the coasts, and the temperatures will fall below freezing during all months of the year. At Point Barrow, Alaska, the minimum temperature fails to fall below freezing on only about 42 days a year. Over the Arctic Ocean the temperatures are very similar to those experienced along the coast; however, the summer temperatures are somewhat colder.

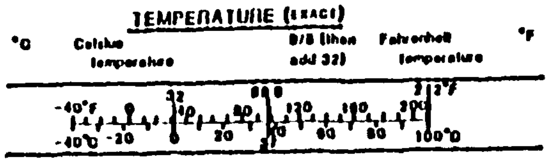
Winter temperatures along the Arctic coast are very cold but not nearly so cold as those observed in certain interior areas. Only on rare occasions does the temperature climb to above freezing during the winter months. The coldest readings for these coastal areas are in the -60's and -70's (degrees Fahrenheit).

The air temperature alone is not the best indicator of how cold one feels if there is any appreciable wind. Using wind speed and temperature the concept of wind chill index or equivalent temperature can be derived (Arkin, 1971). Table 20 shows a wind chill nomogram and a table of wind chill equivalent temperatues which were prepared from the nomogram. To use the nomogram the temperature and wind speed must be known. For example, assume the wind speed is 10 mph and the air temperature is 20°F. Move along the 10 mph line until it intersects the 20°F vertical line. Then move horizontally to the 4 mph line and read the wind chill temperature vertically below this point. (Note: The 4 mph line is always used as the baseline to estimate the wind chill for any set of wind speed and temperature.) (Example: The data line shows that for a 20°F air temperature and a 10 mph wind, the equivalent temperatures is 3°F). The highlighted area of the wind chill equivalent temperature chart shows the same result as the nomogram example.

Table 21 is another example of a wind chill chart. This chart gives the approximate boundaries, for properly clothed persons, where wind chills would be of little danger, considerable danger or very great danger.

The final temperature charts (figures 71 and 72) provide the percentage probability of occurrence of free air temperature for all coastal stations (North Slope) and percentage probabilty of occurrence equivalent chill temperature developed for Barrow, Alaska (Searby, 1971) but valid for all coastal stations (North Slope). The equivalent chill temperature chart indicates the severity of the Arctic environment. Fifty percent of the time during the months of November, December, January, February and March the equivalent chill temperature poses considerable danger to properly clothed persons (table 21).

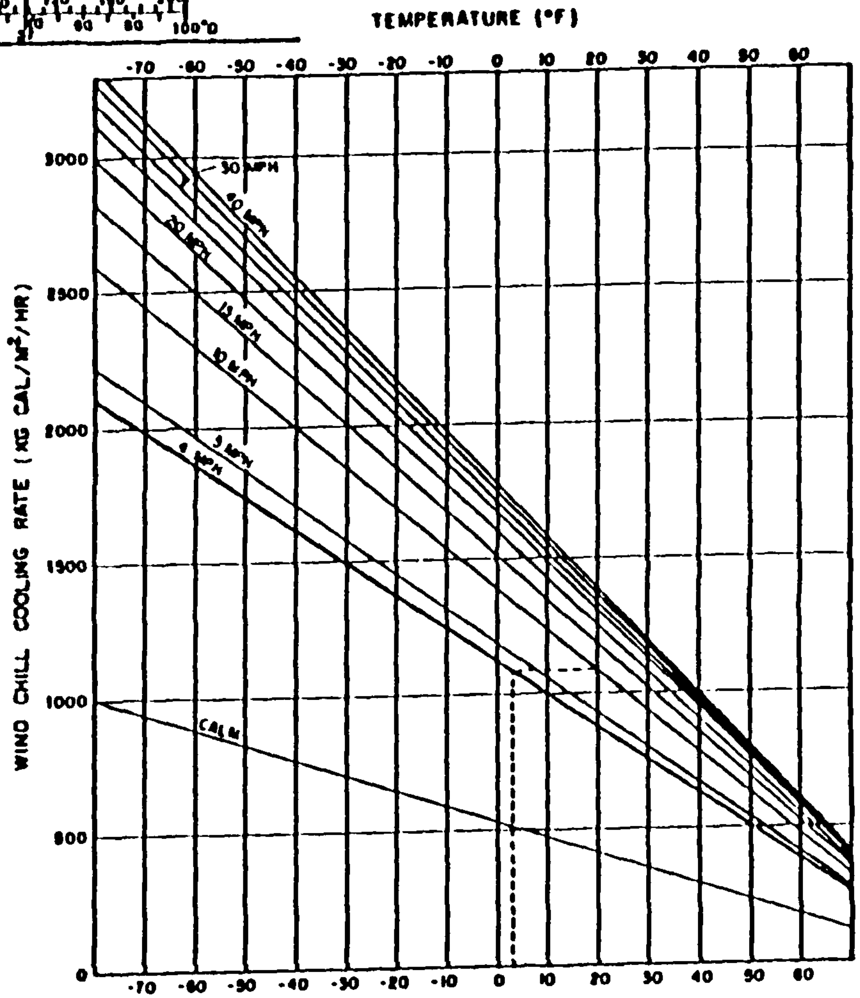
Table 20



WIND VELOCITY (MPH)

DRY BULB TEMPERATURE (°F)	4	8	10	15	20	25	30	35	40	45
45	45	43	34	29	26	23	21	20	19	18
40	40	37	28	23	19	16	13	12	11	10
35	35	32	22	16	12	8	6	4	3	2
30	30	27	16	9	4	1	-2	-4	-5	-6
25	25	22	10	2	-3	-7	-10	-12	-13	-14
20	20	16	3	-5	-10	-15	-18	-20	-21	-22
15	15	11	-3	-11	-17	-22	-25	-27	-29	-30
10	10	6	-9	-18	-24	-29	-33	-35	-37	-38
5	5	0	-15	-25	-31	-36	-41	-43	-45	-46
0	0	-5	-22	-31	-39	-44	-49	-52	-53	-54
-5	-5	-10	-27	-38	-46	-51	-56	-58	-60	-62
-10	-10	-15	-34	-45	-53	-59	-64	-67	-69	-70
-15	-15	-21	-40	-51	-60	-66	-71	-74	-76	-78
-20	-20	-26	-46	-58	-67	-74	-79	-82	-84	-85
-25	-25	-31	-52	-65	-74	-81	-86	-89	-92	-93
-30	-30	-36	-58	-72	-81	-88	-93	-97	-100	-102
-35	-35	-42	-64	-78	-88	-96	-101	-105	-107	-109
-40	-40	-47	-71	-85	-95	-103	-109	-113	-115	-117
-45	-45	-52	-77	-92	-103	-110	-116	-120	-123	-125

a) WIND CHILL EQUIVALENT TEMPERATURE



b) WIND CHILL INDEX NOMOGRAM

Table 21

WIND CHILL CHART DEFINING TEMPERATURES HAZARDOUS FOR PROPERLY CLOTHED PERSONS

WINDCHILL CHART											
	LOCAL TEMPERATURE (°F)										
WIND SPEED (MPH)	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
	EQUIVALENT TEMPERATURE										
CALM	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
5	29	20	10	1	-9	-18	-28	-37	-47	-56	-65
10	18	7	-4	-15	-26	-37	-48	-59	-70	-81	-92
15	13	-1	-13	-25	-37	-49	-61	-73	-85	-97	-109
20	7	-6	-19	-32	-44	-57	-70	-83	-96	-109	-121
25	3	-10	-24	-37	-50	-64	-77	-90	-104	-117	-130
30	1	-13	-27	-41	-54	-68	-82	-97	-109	-123	-137
35	-1	-15	-29	-43	-57	-71	-85	-99	-113	-127	-142
40	-3	-17	-31	-45	-59	-74	-87	-102	-116	-131	-145
45	-3	-18	-32	-46	-61	-75	-89	-104	-118	-132	-147
50	-4	-18	-33	-47	-62	-76	-91	-105	-120	-134	-148
LITTLE DANGER FOR PROPERLY CLOTHED PERSONS			CONSIDERABLE DANGER			VERY GREAT DANGER					
DANGER FROM FREEZING OF EXPOSED FLESH											

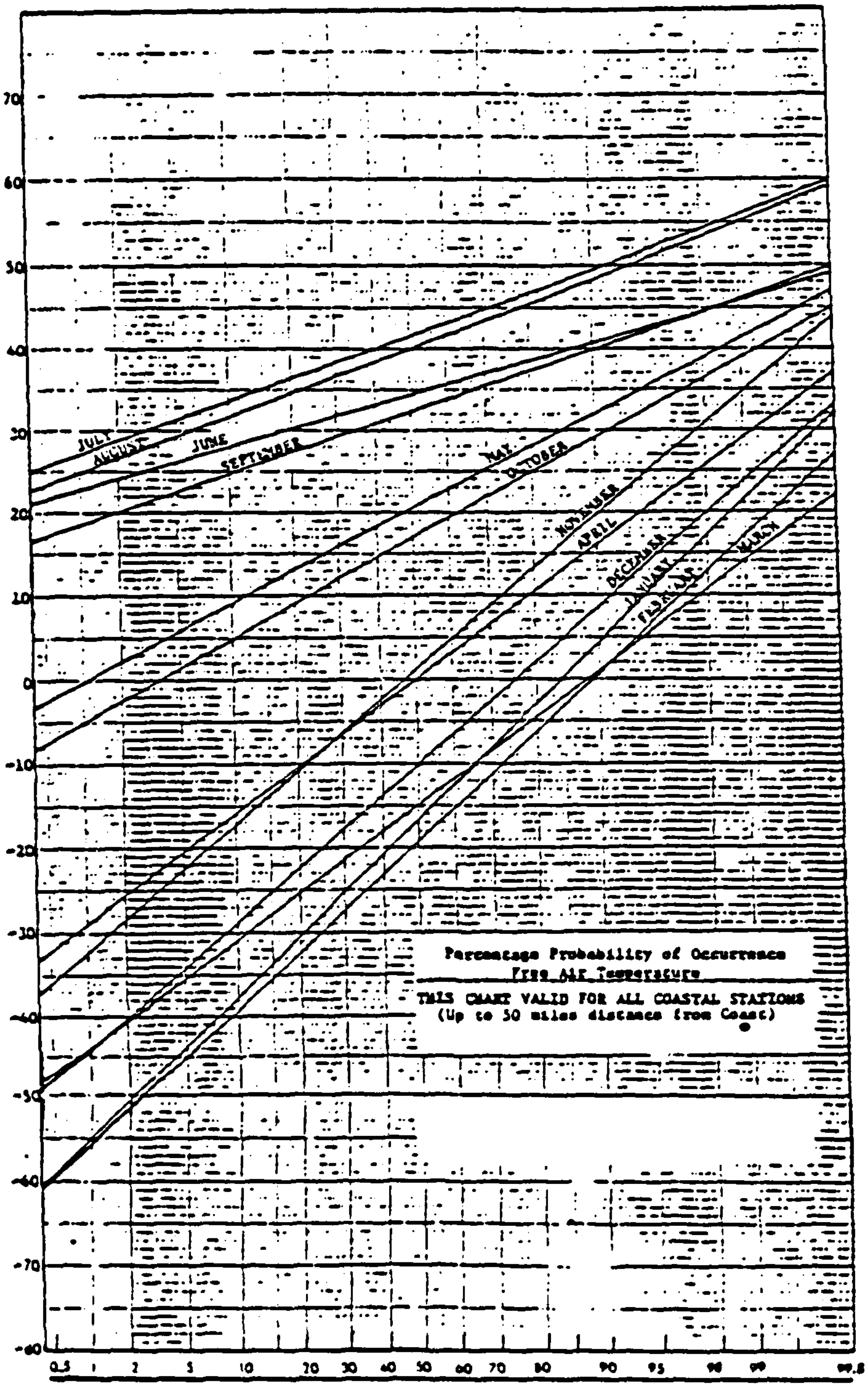


FIGURE 71 - MONTHLY GRAPHS OF THE PERCENTAGE PROBABILITY OF OCCURRENCE OF FREE AIR TEMPERATURES (FROM HARTMAN & JOHNSON, 1978)

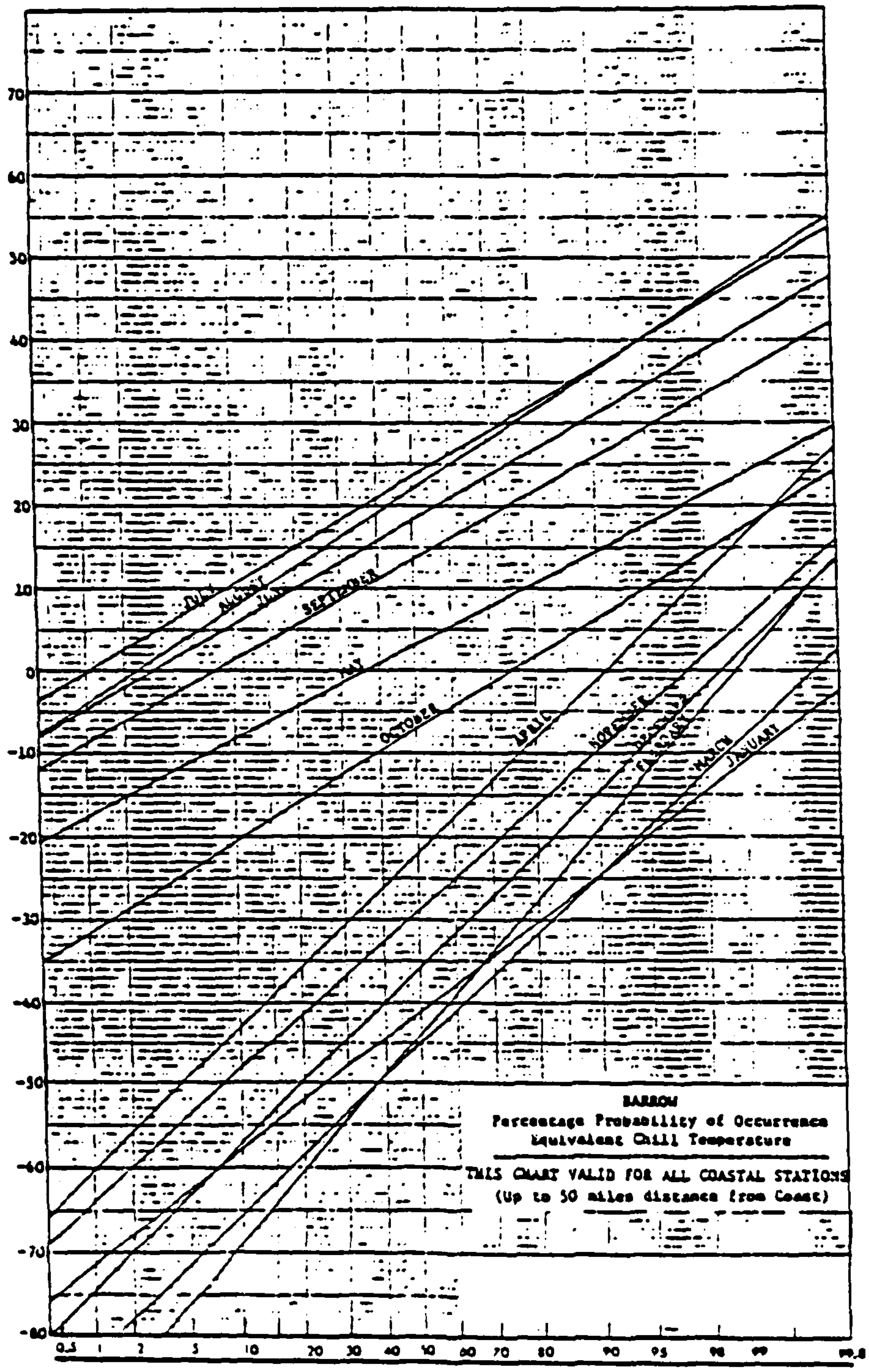


FIGURE 72 - MONTHLY GRAPHS OF THE PERCENTAGE PROBABILITY OF OCCURRENCE OF EQUIVALENT CHILL TEMPERATURE

20.0 VISIBILITY

Two conflicting factors make the subject of visibility in the polar regions very complex. Arctic air being cold and dry, is exceptionally transparent and because of this extreme ranges of visibility are possible. On the other hand, there is a lack of contrast between objects, particularly when all distinguishable objects are covered by a layer of new snow. Limitations to visibility in the Arctic are primarily blowing snow and fog.

1. Blowing snow. Blowing snow constitutes a more serious hazard to operations in the Arctic than in midlatitudes, because the snow is dry and fine and is easily picked up by gentle and moderate winds. Winds in excess of 8 to 12 knots may raise the snow several feet off the ground, and the blowing snow may obscure surface objects.

2. Fog. The two types of fog most frequently found in the polar regions are advection and radiation fog. Fog is found most frequently along the Arctic coastal areas during summers and usually lies in a belt parallel to the shore. Tables 22 and 23 provide monthly percentage frequency of occurrence of visibility and ceiling height for Barter Island and Point Barrow.

Table 22

PERCENTAGE FREQUENCY OCCURRENCE OF CEILING HEIGHT AND VISIBILITY FOR BARTER ISLAND
(FROM SEARBY & HUNTER, 1971)
(1 foot = 0.3048006 m)
(1 mile = 1.60935 Km)

MONTH	CEILING HEIGHT					VISIBILITY						
	0-400 ft.	500-900 ft.	1000-2000 ft.	2100-3000 ft.	> 3000 ft.	0-1/8 mi.	3/16-1/4 mi.	5/16-1/2 mi.	5/8-3/4 mi.	1-2 1/4 mi.	2 1/2 mi.	≥ 3 mi.
01	5.8	2.9	11.7	5.9	73.7	5.8	3.2	3.6	2.0	7.5	.2	77.7
02	7.7	1.6	8.0	4.9	77.8	8.3	3.0	3.4	2.2	7.7	.1	75.3
03	2.5	1.2	7.3	5.5	80.5	3.7	2.3	3.4	2.5	8.3	.4	79.8
04	2.4	5.4	11.3	5.1	75.8	2.7	2.4	2.9	2.4	8.7	.5	80.4
05	11.1	28.4	20.1	6.5	33.9	1.2	2.8	3.5	2.8	10.5	.7	78.5
06	16.0	18.2	12.3	5.2	48.3	2.5	3.5	4.4	3.0	9.0	.5	77.1
07	17.5	9.5	7.1	5.5	60.4	3.9	5.4	4.6	2.2	5.3	.1	78.5
08	22.7	13.4	10.3	5.0	48.6	5.0	6.5	5.0	2.9	7.4	.2	73.0
09	17.2	15.5	21.9	6.9	38.5	3.0	5.0	5.4	3.1	8.7	.2	74.6
10	6.9	15.0	31.0	9.4	37.7	.8	2.2	3.2	3.0	11.2	.2	79.4
11	5.3	11.2	25.0	6.6	51.9	2.6	3.5	3.0	1.9	10.8	.3	77.9
12	3.7	5.6	14.9	7.4	68.4	3.2	1.9	2.6	1.6	8.4	.2	82.1
Yr	9.9	10.8	15.2	6.2	57.9	3.5	3.5	3.7	2.5	8.6	.3	77.9

Table 23

PERCENTAGE FREQUENCY OCCURRENCE OF CEILING HEIGHT AND VISIBILITY FOR POINT BARROW
(FROM SEARBY & HUNTER, 1971)

(1 foot = 0.3048006 m)
(1 mile = 1.60935 Km)

MONTH	CEILING HEIGHT					VISIBILITY						
	0-400 ft.	500-900 ft.	1000-2000 ft.	2100-3000 ft.	> 3000 ft	0-1/8 mi.	3/16-1/4 mi.	5/16-1/2 mi.	5/8-3/4 mi.	1-2 1/4 mi.	2 1/2 mi.	≥3 mi.
01	2.7	4.8	9.0	3.9	79.6	1.5	2.6	2.5	1.4	5.5	.3	86.2
02	3.1	3.8	10.9	3.7	78.5	2.5	1.8	2.9	1.6	8.1	.7	82.8
03	.9	2.9	7.9	5.4	82.9	.3	.5	1.9	1.0	4.8	.3	91.2
04	2.6	7.8	12.4	5.7	71.5	.9	2.0	2.4	1.1	5.0	.2	88.4
05	11.0	29.8	23.3	5.2	30.7	.5	2.0	3.1	1.0	5.6	.1	87.7
06	24.9	21.1	12:8	3.8	37.4	2.5	4.0	4.3	1.8	7.1	.2	80.1
07	16.4	14.9	9.0	4.3	55.4	1.7	2.5	3.8	1.3	5.9	.3	84.5
08	19.4	23.9	19.7	3.9	33.1	1.8	2.3	3.2	1.2	6.0	.3	85.2
09	13.1	31.0	30.9	6.1	18.9	.5	.6	2.1	.8	6.4	.1	89.5
10	7.2	22.1	27.1	8.5	35.1	.8	1.6	2.1	1.5	8.0	.4	85.6
11	4.5	12.0	30.0	7.4	46.1	3.1	2.0	4.4	1.4	8.7	.4	80.0
12	3.8	7.6	17.0	5.2	66.4	1.7	2.5	2.8	.8	8.3	.5	83.4
Yr	9.2	15.1	17.3	5.2	53.2	1.5	2.0	2.9	1.2	6.6	.3	85.5

21.0 PRECIPITATION

Precipitation amounts are small varying from 3 to 7 inches ($\sim$ 7 to 18 cm) along the Arctic coastal area and over the ice pack. The climate over the Arctic Ocean and adjoining coastal areas is as dry as some of the desert regions in the United States. Most of the annual precipitation falls as snow during the winter months. Precipitation statistics are found in taoles 24 and 25.

Table 24

PERCENTAGE FREQUENCY OF OCCURRENCE OF DAILY AMOUNTS OF SNOWFALL AND PRECIPITATION
BARTER ISLAND
(FROM SEARBY & HUNTER, 1971)
(1 inch = 2.54 cm)

SNOWFALL

Month	None	Trace	0.1–0.4	0.5–1.4	1.5–2.4	2.5–3.4	3.5–4.4	4.5–6.4	≥ 6.5	Mean Monthly Snowfall (Inches)	Maximum Monthly Snowfall (Inches)	Mean No. Days with Snowfall ≥ 0.1"
	Monthly values below are percentage frequency of occurrence of daily amounts. Categories below are in inches											
J	45	34	11	6	3	*	1	*	*	6.2	35.0	6.6
F	46	31	15	5	3	*				3.1	15.3	6.4
M	39	39	17	4	*	*				2.8	15.0	6.6
A	42	32	21	4	1	*	*			2.7	12.2	7.8
M	35	45	16	3	1	*			*	3.3	11.1	6.3
J	68	23	5	3	*	*				1.6	7.3	2.8
J	91	7	1	1	*					0.5	2.5	0.6
A	86	8	3	2	*	*				1.7	7.4	2.0
S	54	25	12	5	2	*	*	1	*	6.2	35.8	6.4
O	27	30	22	16	3	1	*	*	*	9.2	32.1	13.3
N	34	38	17	8	2	*	*			5.5	14.9	8.2
D	38	41	16	4	1		*	*		3.8	12.9	6.5
Yr	51	29	13	5	1	*	*	*	*	46.6	35.8	73.3

PRECIPITATION

Month	None	Trace	.01	.02–.05	.06–.10	.11–.25	≥ .26	Mean Monthly Precipitation (Inches)	Mean No. Days with Pcpn ≥ 0.01"	Maximum Monthly (Inches)	Minimum Monthly (Inches)	Maximum in 24 Hrs (Inches)
	Monthly values below are percentage frequency of occurrence of daily amounts. Categories below are in inches											
J	44	35	5	8	3	4	2	0.40	6.7	4.08	0.01	2.25
F	46	32	5	10	3	3	*	0.35	6.2	2.53	T	1.22
M	39	39	8	11	2	1	*	0.20	6.6	1.44	T	0.55
A	40	35	10	12	1	1	1	0.17	7.6	1.22	T	0.44
M	29	51	9	8	2	1	*	0.25	6.4	1.51	T	0.76
J	34	44	4	9	3	5	1	0.51	6.5	2.09	0.06	1.15
J	30	41	4	9	6	6	4	0.88	9.1	2.79	0.15	1.17
A	32	333	5	14	5	8	4	1.05	11.1	3.40	0.16	1.11
S	27	40	9	12	4	6	3	0.94	9.9	4.91	0.07	2.23
O	24	32	9	18	9	7	1	0.84	13.8	3.62	0.12	1.98
N	34	38	9	11	5	3	*	0.40	8.3	1.50	0.04	0.43
D	38	41	7	11	2	1	*	0.29	6.5	1.17	T	0.55
	34	39	7	11	4	4	1	6.28	99.3	4.91	T	2.25

* means < 0.5 .   Precipitation includes the water equivalent of snow.

Table 25

PERCENTAGE FREQUENCY OF OCCURRENCE OF DAILY AMOUNTS OF SNOWFALL AND PRECIPITATION
POINT BARROW
(FROM SEARBY & HUNTER, 1971)
(1 inch = 2.54 cm)

SNOWFALL

Month	None	Trace	0.1-0.4	0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-6.4	≥ 6.5	Mean Monthly Snowfall (Inches)	Maximum Monthly Snowfall (Inches)	Mean No. Days with Snowfall ≥ .01"
	Monthly values below are percentage frequency of occurrence of daily amounts. Categories below are in inches											
J	36	48	12	3	1					2.4	11.9	5.1
F	32	49	14	5						2.3	9.4	5.3
M	29	56	14	1						2.0	15.8	4.8
A	37	45	13	5	*					2.2	15.4	5.4
M	18	68	11	3						2.0	12.9	4.4
J	56	38	4	1	1					0.5	6.6	1.6
J	88	11	1	*				None	None	0.7	9.0	0.4
A	71	25	4	*						0.7	4.0	1.4
S	32	48	16	4			*			2.9	7.9	6.2
O	19	40	28	12	1					7.0	21.2	12.7
N	24	44	24	8						3.7	19.0	9.7
D	26	55	17	2						2.8	9.7	5.8
Yr	39	44	13	4	*		*			29.2	21.2	62.8

PRECIPITATION

Month	None	Trace	.01	.02-.05	.06-.10	.11-.25	≥ .26	Mean Monthly Precipitation (Inches)	Mean No. Days with Pcpn ≥ 0.01"	Maximum Monthly (Inches)	Minimum Monthly (Inches)	Maximum in 24 Hrs. (Inches)
	Monthly values below are percentage frequency of occurrence of daily amounts. Categories below are in inches											
J	35	50	5	8	1	1		0.18	4.7	1.04	0.00	0.70
F	33	49	9	7	2	*		0.17	5.1	0.81	0.00	0.36
M	28	58	6	6	1	*		0.11	4.1	1.49	0.00	0.71
A	37	47	7	7	2			0.11	4.6	1.36	0.00	0.42
M	15	71	7	6	1	*		0.12	4.3	0.81	T	0.30
J	24	57	6	8	2	2	1	0.36	5.8	1.15	T	0.82
J	34	39	5	12	3	4	3	0.77	8.3	2.44	T	0.86
A	14	41	11	16	6	9	3	0.90	13.8	2.81	T	0.83
S	12	55	12	13	5	1	2	0.64	9.9	1.56	0.01	0.56
O	17	44	13	18	5	3		0.50	12.0	1.65	0.12	1.00
N	24	46	11	16	3			0.23	9.1	1.15	T	0.41
D	27	56	9	7	*	1		0.17	5.3	0.76	0.00	0.26
	25	51	8	10	3	2	1	4.26	87.0	2.81	0.00	1.00

* means < 0.5. Precipitation includes the water equivalent of snow.

22.0. CLIMATOLOGICAL PARAMETERS

Climatological parameters for Point Barrow and Barter Island are summarized in tables 26-29.

Table 26

CLIMATOLOGICAL SUMMARIES FOR POINT BARROW AND BARTER ISLAND
(1 knot = 0.5148 m/s)
(1 inch = 2.54 cm)

BARROW, ALASKA (Airport Station), 71°18'N., 156°47'W.; Elevation (ground) 22 feet.

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 8:00 a.m. Local time	2:00 p.m. Local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				41	41		40	41	17	17	32	12			20	27	27	27	41	17	41	28
Jan.	-8.5	-21.6	-15.1	33	-53	0.16	0.70	2.1	63	62	9.5	ESE			0	3	3	2	4	1	0	2
Feb.	11.4	-24.3	-17.9	32	-56	0.15	0.38	2.2	62	61	9.8	ENE			3.3	12	6	10	4	•	0	1
Mar.	-7.8	-21.9	-14.9	30	-52	0.12	0.28	1.6	62	64	9.6	ENE			5.0	14	7	10	3	•	0	1
Apr.	7.4	-7.7	-0.2	42	-42	0.10	0.37	1.8	72	73	10.0	NE			5.8	11	7	12	3	1	0	3
May	24.4	13.2	18.8	45	-18	0.12	0.30	1.6	87	85	10.3	ENE			8.4	4	4	23	3	•	0	8
June	38.9	28.9	33.9	70	8	0.28	0.82	0.4	93	90	9.9	E			8.0	5	5	20	4	•	•	12
July	46.0	33.3	39.7	78	22	0.85	0.86	0.7	93	88	10.2	E			8.2	3	7	21	8	•	•	13
Aug.	43.7	33.0	38.4	73	20	0.80	0.83	0.6	94	90	11.0	E			9.0	2	3	26	10	•	•	11
Sep.	34.2	27.0	30.6	62	1	0.55	0.54	2.9	92	89	11.3	E			9.3	2	3	25	9	1	0	5
Oct.	22.0	12.1	17.1	43	-19	0.52	1.00	6.9	85	84	11.3	E			8.8	2	4	25	10	2	0	4
Nov.	6.6	-5.3	0.7	38	-40	0.27	0.41	3.5	75	74	10.9	E			0	4	3	10	6	•	0	2
Dec.	-4.2	-16.6	-10.4	34	-55	0.20	0.28	2.7	65	65	10.0	ENE			0	0	0	0	5	•	0	2
Year	15.8	4.2	10.1	78	-56	4.11	1.00	27.0	79	77	10.3	E			-	62	51	184	69	8	•	65

BARTER ISLAND, ALASKA (Airport Station), 70°08'N., 143°38'W., Elevation (ground) 38 feet.

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum in 24 hrs.	Snow, sleet, mean total	Humidity (percent): 8:00 a.m. Local time	8:00 p.m. Local time	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)				12	14		13	13	14	14	13	13			13	13	13	13	12	13	12	13
Jan.	-9.4	-22.3	-15.9	37	-50	0.39	1.20	5.3	69	68	11.8	E			0	4	2	8	6	1	0	1
Feb.	[illegible]	-25.2	[illegible]	34	-59	0.35	[illegible]	3.3	66	67	12.9	W			5.1	10	7	11	5	1	0	1
Mar.	-8.3	-22.1	-14.3	31	-50	0.26	0.44	2.3	66	67	11.1	W			5.9	8	10	13	6	1	0	2
Apr.	9.3	-7.3	1.0	43	-37	0.19	0.27	2.2	73	74	10.7	W			6.4	7	8	15	7	•	0	3
May	25.3	[illegible]	20.3	48	-14	0.22	0.76	3.0	86	85	[illegible]	E			8.3	3	5	23	7	1	0	8
June	40.4	30.2	35.3	67	18	0.42	[illegible]	1.5	90	89	9.4	ENE			8.1	2	8	20	7	•	•	11
July	47.9	34.6	40.8	71	25	1.18	1.17	0.4	90	87	8.9	ENE			7.9	2	10	18	10	•	•	15
Aug.	44.4	34.0	39.2	72	24	1.18	1.11	1.5	92	88	10.4	E			8.5	1	8	22	11	1	0	15
Sep.	34.3	[illegible]	31.3	54	7	[illegible]	2.23	7.8	91	90	11.0	E			8.6	1	8	23	10	2	0	11
Oct.	[illegible]	[illegible]	[illegible]	[illegible]	-15	[illegible]	[illegible]	11.1	86	85	[illegible]	E			5.5	2	5	[illegible]	14	6	0	7
Nov.	8.6	-3.7	0.5	37	-51	0.58	0.43	4.8	76	75	12.6	E			0	4	4	15	9	1	0	3
Dec.	-4.4	-17.4	-10.9	30	-51	0.46	0.35	2.9	68	70	12.1	W			0	0	0	0	6	1	0	1
Year	16.8	4.4	10.6	72	-59	7.18	2.23	46.1	79	78	11.2	E			-	44	74	192	98	13	•	74

Table 27

PERCENTAGE FREQUENCY OF OCCURRENCE OF WEATHER CONDITIONS FOR POINT BARROW, BARTER ISLAND AND UMIAT (AN INLAND STATION)
(FROM SEARBY & HUNTER, 1971)

	Thunder-storms			Rain and/or Drizzle			Freezing Rain			Snow and/or Sleet			Percentage Obs. with Pcpn			Fog			Smoke and/or Haze			Blowing Snow			Percentage Obs. with Obstr. to Vision		
MONTH	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat	Barter Is.	Barrow	Umiat
Jan		.0		.2	.1	.1	.1	.7	.3	19.3	29.2	35.5	19.6	29.9	35.7	6.9	12.5		.1	.5		20.2	13.7		26.6	24.7	
Feb			.1					.1		20.4	30.3	37.9	20.4	30.4	37.9	8.0	13.1		.1	.3		22.3	12.6		29.2	25.3	
Mar		.0			.0			.0		19.6	26.7	34.6	19.6	26.7	34.7	9.7	7.9	Not Available	.1	.2	Not Available	16.8	10.0	Not Available	24.9	17.3	Not Available
Apr			.1	.3	.1	.3	.1	.3	.2	21.7	27.7	30.0	22.0	28.1	30.3	11.8	9.3		.2	.2		11.5	7.8		22.7	16.7	
May	.0			1.6	.6	1.3	2.4	2.2	1.5	24.7	33.5	21.8	28.3	35.8	24.2	25.1	17.4		.0	.0		3.3	4.0		27.5	21.0	
Jun	.0	.6		8.6	9.1	13.4	1.2	1.4	.3	8.6	12.0	6.1	18.3	22.1	19.5	26.6	26.4		.1	.0		.1	.5		26.7	26.9	
Jul	.1	.1	.2	16.0	14.5	12.5	.2	.4		1.7	3.2	.1	17.8	17.9	12.7	25.3	25.9		.0						25.3	25.9	
Aug		.1		17.1	19.3	18.8	.2	.7	.2	4.2	8.4	4.7	21.5	28.1	22.9	31.5	25.5		.1	.0			.0		31.6	25.5	
Sep				9.6	8.6	10.5	.9	2.2	1.2	16.2	25.5	22.3	26.6	35.6	33.5	26.6	17.7		.0			1.9	.7		28.3	18.2	
Oct				.6	.8	.5	1.9	1.6	1.3	33.1	43.1	37.7	35.3	45.2	39.4	13.5	13.0		.2	.0		10.4	7.7		22.6	20.9	
Nov				.1	.0		.4	.6	.5	29.0	36.7	47.3	29.5	37.3	47.7	9.8	10.5		.1	.0		17.6	16.3		25.0	26.0	
Dec					.0		.0	.1	.2	25.8	33.1	50.5	25.8	33.2	50.6	8.0	10.4		.1	.1		16.6	13.5		23.7	22.5	
Avg	.0	.0		4.6	4.5	4.9	.6	.9	.5	18.7	25.7	26.9	23.8	30.9	32.1	17.0	15.8		.1	.1		9.9	7.2		26.1	22.6	

Table 28

MONTHLY VALUES OF PERCENTAGE FREQUENCY OF OCCURRENCE OF SNOW DEPTH, VISIBILITY AND SKY COVER
POINT BARROW
(FROM SEARBY & HUNTER, 1971)
(1 inch = 2.54 cm)

Month	SNOW DEPTH: MONTHLY VALUES BELOW ARE PERCENTAGE FREQUENCY OF OCCURRENCE (BASED ON HOURLY OBSERVATIONS) — CATEGORIES BELOW ARE IN INCHES												VISIBILITY: PERCENTAGE FREQUENCY OF OCCURRENCE — Hourly Obsns/w Vsby <1 mi., caused by:					SKY COVER: PERCENTAGE FREQUENCY OF OCCURRENCE OF SKY COVER (BASED ON HRLY OBSERVATIONS) — CATEGORIES BELOW ARE TENTHS OF TOTAL SKY COVER					
	None	Trace	1	2	3	4-6	7-12	13-24	25-36	37-48	Mean Snow Depth in Inches	Mean No. Days with Snowfall ≥ 0.1"	Fog	Smoke and/or Haze	Blowing Snow and/or Dust	Precip-itation	Total obsns vsby < 1 mi.	0-3	4-5	6-7	8-9	10	Avg Sky Cover in Tenths
J						20	55	25			9.8	31.0	3.5	.1	4.1	.2	7.9	53.2	4.0	4.3	5.3	33.2	4.4
F						2	48	50			12.1	28.0	1.8		6.6	.3	8.7	50.4	3.7	4.8	6.2	34.9	4.7
M							50	50			12.5	31.0	1.0		2.5	.3	3.7	45.8	5.2	5.8	8.7	34.5	5.0
A							50	50			13.7	30.0	3.0		2.7	.6	6.3	41.2	4.2	4.7	7.8	42.1	5.5
M				1		14	55	30			11.4	31.0	6.1		.3	.3	6.6	13.7	2.1	2.8	6.2	75.2	8.4
J	17	34	11	13	6	6	11	2			2.2	14.8	12.4		.1	.1	12.7	13.2	4.1	4.7	10.0	68.0	8.3
J	94	6									T	0.0	9.4				9.4	13.3	4.6	5.6	14.3	62.2	8.2
A	90	10									T	0.0	8.3			.1	8.4	4.7	1.8	2.8	8.5	82.2	9.3
S	52	38	3	4	3						0.2	3.5	3.7		.1	.3	4.1	4.4	1.7	2.1	6.8	85.0	9.3
O		12	9	29	13	24	13				3.2	27.2	3.4		1.7	1.0	6.1	11.0	3.0	4.1	8.3	73.6	8.6
N				7	2	44	43	4			6.6	30.0	3.6		6.8	.5	10.8	21.0	3.8	4.8	7.4	63.0	7.6
D						33	57	10			8.7	31.0	2.5		5.2		7.8	40.4	4.0	4.3	5.9	45.4	5.7
Yr	21	8	2	5	2	12	32	18			6.7	257.5	4.9	*	2.5	.3	7.7	26.0	3.5	4.2	8.0	58.3	7.1

* means < 0.5

Table 29

MONTHLY VALUES OF PERCENTAGE FREQUENCY OF OCCURRENCE OF SNOW DEPTH, VISIBILITY AND SKY COVER
BARTER ISLAND
(FROM SEARBY & HUNTER, 1971)
(1 inch = 2.54 cm)

	SNOW DEPTH												VISIBILITY					SKY COVER					
	MONTHLY VALUES BELOW ARE PERCENTAGE FREQUENCY OF OCCURRENCE (BASED ON HOURLY OBSERVATIONS) — CATEGORIES BELOW ARE IN INCHES												PERCENTAGE FREQUENCY OF OCCURRENCE — Hourly Obsns/w Vsby <1 mi., caused by:					PERCENTAGE FREQUENCY OF OCCURRENCE OF SKY COVER (BASED ON HRLY OBSERVATIONS) — CATEGORIES BELOW ARE TENTHS OF TOTAL SKY COVER					
Month	None	Trace	1	2	3	4-6	7-12	13-24	25-36	37-48	Mean Snow Depth in Inches	Mean No. Days with Snowfall ≥ 0.1"	Fog	Smoke and/or Haze	Blowing Snow and/or Dust	Precip-itation	Total obsns vsby < 1 mi.	0-3	4-5	6-7	8-9	10	Avg Sky Cover in Tenths
J						9	31	37	21	2	15.9	31.0	1.6		12.2	.8	14.6	42.4	5.6	6.6	7.6	37.8	5.3
F						2	17	56	18	7	19.6	28.0	2.0	.0	14.3	.6	16.9	44.3	6.2	5.7	7.4	36.4	5.2
M						1	19	47	20	13	21.2	31.0	2.7	.0	9.0	.2	11.9	42.2	6.3	7.3	9.9	34.3	5.3
A						6	29	29	26	10	19.5	30.0	3.7		5.8	.9	10.4	34.8	5.6	6.6	10.5	42.6	6.1
M			2	2	4	14	25	38	13	2	14.2	31.0	9.0		.8	.5	10.3	14.1	3.2	4.0	8.2	70.5	8.3
J	16	33	12	6	8	7	10	6	2		3.4	15.4	13.0		.1	.4	13.5	15.1	5.0	6.2	13.4	60.4	8.0
J	87	12	1	*							T	0.5	16.1			.1	16.2	15.5	6.1	7.3	15.3	55.9	7.9
A	95	3	2	*							T	0.9	19.1			.3	19.4	9.6	4.5	5.7	14.0	66.2	8.5
S	53	25	9	4	2	2	2	3			1.0	6.6	14.7		.8	.9	16.4	12.2	3.9	4.8	10.3	68.9	8.4
O	7	11	5	8	7	34	20	8			5.3	25.4	5.1		2.6	1.4	9.1	14.8	3.8	4.2	8.1	68.9	8.2
N	*				4	26	46	24			9.4	29.9	3.8		6.5	.7	11.0	27.4	4.4	4.6	7.5	56.1	6.9
D						16	40	35	9		12.4	31.0	2.1		6.4	.8	9.3	38.4	5.4	5.8	7.3	43.0	5.8
Yr	22	7	2	2	2	10	20	23	9	3	10.0	260.7	7.8	.0	4.8	.6	13.2	25.7	5.0	5.7	10.0	53.6	7.0

* means < 0.5

23.0. CASE HISTORIES

The following fourteen case histories provide descriptive information for severe storm surges between 1954 and 1977.

STORM PROFILE: 1
REGIONS: West Arctic
COMMUNITIES: Barrow
INCLUSIVE DATES: 17/9/1954 TO 18/9/1954
DAMAGE, Barrow: Water washed over the beach into camp, a helium tank from Barrow village was moved almost to the point.
MAXIMUM SURGE: 9 to 10 ft in Barrow
DATA SOURCES: 8.0

STORM PROFILE: 2
REGIONS: West Arctic
COMMUNITIES: Barrow, Wainwright
INCLUSIVE DATES: 3/10/1954 TO 5/10/1954
DAMAGE: Minor damage. Wainwright had beach erosion, goods were moved from store, and a scow was washed 4 miles to east and buried in sand.
MAXIMUM SURGE: 9.5 ft
COMMENTS: Only known reference is by Hume. The 1954 storm was the strongest prior to the October 1963 storm.
DATA SOURCES: 8.0, 5.0

STORM PROFILE: 3
REGIONS: East Arctic
COMMUNITIES: Barter Island
INCLUSIVE DATES: 19/9/1957 TO 21/9/1957
DAMAGE: Road damage, 4,400 barrels of fuel washed away. Part of runway undermined. Navy LST ran aground.
MAXIMUM SURGE: 6-12 ft
DATA SOURCES: 8.0

STORM PROFILE: 4
REGIONS: West Arctic, Colville, East Arctic
COMMUNITIES: Barrow, Barter Island, Point Lay, Wainwright
INCLUSIVE DATES: 3/10/1963 TO 3/10/63
DAMAGE: $3 million to Barrow. 15 homes plus 15 other buildings and contents, 4 airplanes, freshwater supply contaminated with sea water, electrical generating plant received $100,000 damage. Sediment transport was the equivalent of 20 years normal transport. Water depths 2 ft at ARL Laboratory, 3.5 ft in other areas. Wainwright 50% flooded, 4 ft water to top of bluff.
MAXIMUM SURGE: Barrow 11-12 ft; Barter Is. 5.5 ft; Pt. Lay 9 ft; Wainwright 4 ft
COMMENTS: A deepening low pressure center 995 to 980 mb moved from 74N 163W to 74N 120W at 25-30 knots in 24 hours. Surge developed in west to northwest flow, south of storm.
DATA SOURCES: 8.0, 5.0, 3.0

STORM PROFILE: 5
REGIONS: Western Arctic
COMMUNITIES: Barrow, Pt. Barrow
INCLUSIVE DATES: 21/9/1968 TO 24/9/1968
DAMAGE: $50,000. Road between Barrow and city dump (3 mi) eroded severely and a bridge damaged.
MAXIMUM SURGE: 8.5 ft
COMMENTS: A storm moving west to east at 15 kts, 200 miles north of Barrow, brought 25 ft waves offshore
DATA SOURCES: 1.0, 3.0, 5.0

STORM PROFILE: 6
REGIONS: West Arctic, East Arctic
COMMUNITIES: Oliktok, Prudhoe Bay, Barrow
INCLUSIVE DATES: 13/9/1970 TO 13/9/1970
DAMAGE: Oliktok lost several hundred ft of runway, driftwood lines indicated a surge of approximately 3 meters.
MAXIMUM SURGE: 3 m at Oliktok; 3 m approx. at Prudhoe; 2.4 and 3 m at Herschel
COMMENTS: No weather reports except Barrow. Winds from reference: Oliktok 80 km/hr (50 mph); Deadhorse 46 km/hr; Cape Haklett 130 km/hr (estimated).
DATA SOURCES: 18.0

STORM PROFILE: 7
REGIONS: East Arctic
COMMUNITIES: Prudhoe Bay
INCLUSIVE DATES: 28/11/1970 TO 28/11/1970
COMMENTS: Storm center causing flooding 27/11/70 at Kotzebue curved near Barrow to move east at 25 kt to 72N, 45W at 28/1200Z.
DATA SOURCES: 15.0

STORM PROFILE: 8 .
REGIONS: East Arctic
COMMUNITIES:
INCLUSIVE DATES: 2/9/1972 TO 2/9/1972
MAXIMUM SURGE: 3.8 ft
COMMENTS: A 996 mb low pressure center moved from west to east 200 nmi north of the coast. Surge occurred in northwesterly flow southwest of the storm.
DATA SOURCES: 6.0

STORM PROFILE: 9
REGIONS: East Arctic
COMMUNITIES:
INCLUSIVE DATES: 27/9/1972 TO 27/9/1972
COMMENTS: Ship at MSQ 268/13 reported 14 kts W with 5 ft waves, 5 sec. period. Same ship next at MSQ 268/12 at 2100Z 9-28-72 reports wind 15 kts W, with 15 ft waves 6-7 sec. period.
DATA SOURCES: 15.0

STORM PROFILE: 10
REGIONS: West Arctic
COMMUNITIES: Point Lay
INCLUSIVE DATES: 9/10/1972 TO 10/10/1972
COMMENTS: A 980 mb low pressure system moved from 62N 177W to 74N 153W at 25 knots in 36 hours. Surge occurred with southwest winds in the southeast quadrant of the storm.
DATA SOURCES: 4.0

STORM PROFILE: 11
REGIONS: East Arctic
INCLUSIVE DATES: 5/1/1974 TO 7/1/1974
COMMENTS: Maximum winds on record at Barter Island occurred with an estimated 990 mb low pressure center moving west to east 300 nmi north of the Beaufort Sea coast.
DATA SOURCES: 6.0

STORM PROFILE: 12
REGIONS: West Arctic, Colville, East Arctic
INCLUSIVE DATES: 26/8/1975
DAMAGE: Unknown
MAXIMUM SURGE: 9.5 ft
COMMENTS: The 1975 Prudhoe Bay Sealift fleet was stopped for several days. One barge in the fleet went aground. Driftwood line indicated surge height of 9.5 to 10.0 ft in places. Surge heights highest in sector 1 determined by driftwood lines (Reimnitz and Maurer).
DATA SOURCES: 3.0, 4.0

STORM PROFILE: 13
REGIONS: West Arctic
COMMUNITIES: Icy Cape
INCLUSIVE DATES: 26/8/1975 TO 27/8/1975
DAMAGE: High water and flooding at Icy Cape
MAXIMUM SURGE: Unknown
COMMENTS: The remains of tropical storm Rita moved north/northeast at 30-35 kts from 67N, 174W to 77N 149W in 12 hours.
DATA SOURCES: 4.0

STORM PROFILE: 14
REGIONS: West Arctic
COMMUNITIES: Barrow, Barrow Gas Wells
INCLUSIVE DATES: 29/12/1977 To 30/12/1977
DAMAGE: On the morning of December 30, rising water lifted the pack ice at Barrow and wind drove it as much as 30 yds inland. Barrow gas well runway partially flooded with 6 to 18 in of water rising through a crack in the ice.
MAXIMUM SURGE: 3.5 ft
COMENTS: A storm moved north at 40-50 knots from the Aleutians thru Bering Strait to northwest of Barrow. Southwesterly winds along the Chuckchi coast persisted 12 hours.
DATA SOURCES: 5.0, 3.0

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